Methyl Bromide Field Operation Guidance (MB FOG) Report

April 13, 2015

Based on an Operational Decontamination Assessment of Methyl Bromide Fumigant on *Bacillus anthracis* Sterne

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Acronyms and Abbreviations

AAMP	Ambient Air Monitoring Plan
ACGIH	American Conference of Governmental Industrial Hygienists
B	*Bacillus*
Ba	*Bacillus anthracis*
BI	biological indicator
CAA	Clean Air Act
CBRN	Chemical, Biological, Radiological, and Nuclear
cfm	cubic feet per minute
CFU	colony forming unit(s)
ClO_2	chlorine dioxide gas
CMAD	CBRN Consequence Management and Advisory Division
CRZ	Contaminant Reduction Zone (“warm zone”)
CT	concentration times time (dose)
CUE	critical use exemption
°C	degrees Celsius
DHS	Department of Homeland Security
EPA	Environmental Protection Agency
ERT	Environmental Response Team
EtO	ethylene oxide
EVOH	ethylene vinyl alcohol
EZ	Exclusion Zone (“hot zone”)
FAWN	Florida Automated Weather Network
FID	Flame ionization detector
ft	feet
ft^3	cubic feet
GAO	Government Accountability Office
HASP	Health and Safety Plan
HAZWOPER	Hazardous Waste Operations and Emergency Response
HBr	hydrogen bromide
hr	hour
ID	inner diameter
lb	pound
m^2	square meter
m^3	cubic meter
MB	methyl bromide, bromomethane, CH_3Br
MET	Metrological
mg/L	milligrams per liter
mg/L-hr	milligrams per liter times hour(s)
MOP	method of procedure
NHSRC	National Homeland Security Research Center
NIOSH	National Institute for Occupational Safety and Health
OEL	occupational exposure limits

OSHA	Occupational Safety and Health Administration
PBST	phosphate buffered saline with Tween20
PEL	permissible exposure limit
PID	Photoionization detector
PPE	personal protective equipment
ppm	parts per million
PVC	polyvinyl chloride
QAPP	Quality Assurance Project Plan
QPS	quarantine and pre shipment
QUIC	Quick Urban & Industrial Complex Dispersion Modeling System
RAP	Remediation Action Plan
REL	recommended exposure limit
RH	relative humidity
RTP	Research Triangle Park
SAP	Sampling and Analysis Plan
SCBA	self-contained breathing apparatus
SERAS	Scientific, Engineering, Response and Analytical Services
SPM	single point monitor
SZ	Support Zone (“cold zone”)
T	temperature
tarp	tarpaulin
TLV	threshold limit value
TSA	trypticase soy agar
TWA	time-weighted average
UF	University of Florida
U.S.	United States
USDA	United States Department of Agriculture
USGS	United States Geological Service
VHP	vaporized hydrogen peroxide
VOC	Volatile organic chemicals

Executive Summary

To better understand the use of methyl bromide (MB) in an operational environment, specifically its ability to inactivate *Bacillus anthracis* (*Ba*) contamination in structures, a University of Florida (UF) 1,444 cubic meters (51,000 cubic feet [ft^3]) house was fumigated with MB at 212 milligrams per liter (mg/l) (212 ounces per 1000 ft^3) on December 9-11, 2013. The fumigant, MB, was selected because it has shown to be efficacious in the inactivation of *Ba* spores during laboratory testing; MB is less corrosive than most alternative fumigants; and MB can be captured on activated carbon, mitigating the potential ozone depleting effects. The study was conducted by: the United States Environmental Protection Agency (EPA) Chemical, Biological, Radiological, and Nuclear Consequence Management and Advisory Division; the UF; EPA's National Homeland Security Research Center (NHSRC); EPA's Environmental Response Team; three EPA Region 4 On-Scene Coordinators; and several contractors.

Three 24 x 30 meters (80 x 100 feet) sections of MB resistant tarpaulins (tarps), made from ethylene vinyl alcohol, were hoisted onto the roof and arranged to cover the entire house by the tenting contractor. The sections were joined by overlapping and rolling adjacent edges together and binding them with clamps, while the tarp skirt and apron were weighted to the ground directly below the roof line with 18 kilograms (kg) (40 pound [lb]) sand "snakes". To add strength and protect the first tarp in the event of strong winds; a second tarp was placed over the first tarp and secured in the same manner. Interior preparation of the house included placing seven 85 cubic meters per minute (3,000 cubic feet per minute) fans, four 1,500-watt radiant heaters, and 16 warm-steam vaporizers to help maintain temperature, and relative humidity (RH) equilibrium throughout the house.

Spores of *Ba* Sterne 34F2, the vaccine strain, were used as surrogates in lieu of using virulent *Ba* spores and placed on coupon materials. Two coupon material types, glass and wood, were chosen for preparation of customized biological indicators (BIs) as these materials were found in laboratory studies to be most resistant to *Ba*-spore inactivation using MB. Test coupons (87 glass slides and 87 wood discs) were inoculated with approximately 1 x 10^6 colony forming units of *Ba* Sterne per coupon and were placed at 22 separate locations throughout the house. All coupons were analyzed by the EPA NHSRC Research Triangle Park Microbiology Lab.

An activated carbon scrubber system was rented and used for the study to mitigate the release of MB into the environment. The system consisted of two scrubber vessels each containing approximately 2,495 kg (5,500 lb) of activated carbon, a blower, duct, and fittings. The inlet to the scrubber system was installed in the office-room window located on the northeastern side of the house.

Ambient air monitoring was achieved by placing photoionization monitors at six stationary locations around the house. In addition, hand-held monitors with the same technology were used to leak test the tenting materials and to provide monitoring at those locations not covered by the six stationary monitors. Monitors detected small leaks near the tented house enabling leak-reduction measures to be deployed as needed. Ultimately, the monitors proved effective

and provided a successful health protection measure for the site workers, as well as offsite people.

Liquid MB was released gravimetrically from commercial cylinders, gasified using a propane-fueled heat exchanger, and then introduced into the house at approximately 66 degrees Celsius (°C). Temperature, RH, and concentration of MB were monitored inside the house and were maintained above the set points of 27 °C, 75%, and 212 mg/l, respectively, throughout the fumigation. The activated carbon scrubber was effectively deployed and used to reduce the concentration of MB inside the house from approximately 55,000 parts per million (ppm) to below 150 ppm in 4 hours. Of the 243 kg (536 lb) of MB entering the scrubber at the end of the 48-hour fumigation, a total of 241 kg (532 lb) of MB were captured by the carbon beds, 99% efficient. After the fumigation, all test coupons were removed from the house and incubated for growth potential. All of the 174 coupons were negative for growth.

Based upon the lessons learned during this operational study, and after the test was completed, the Health and Safety Plan and the Ambient Air Monitoring Plan for this operational fumigation test were revised and are available (as attachments) for the response community to use and adapt to site-specific requirements. Based on this field study, it is recommended that the temperature, RH, and concentration of MB be maintained above the set points of 27 °C, 75%, and 212 mg/l, respectively, for 36 hours when fumigating a structure for *Ba*. Additionally, a guidance document was written to review the tactical use of MB as a fumigant for inactivation of *Ba*. Completeting this operational study and updating the operational documents provides EPA with a greater resiliency and capacity to respond to and recover from a *Ba* release or other biological incident.

1. Introduction

The United States Environmental Protection Agency (U.S. EPA) in partnership with the University of Florida (UF) conducted an operational test to further develop results supporting methyl bromide (MB) fumigation as a *Bacillus anthracis* (*Ba*) decontaminant. The test was conducted in an effort to gain large-scale information on the use of MB as a structural fumigant for decontamination of *Ba* spores and to develop site-specific plans and guidance that could be modified and employed in a real-world incident.

The operational fumigation took place on December 9-11, 2013, at a house located on the UF Campus in Davie, FL. Project planning, coordination, and execution involved members from: EPA's Chemical, Biological, Radiological, and Nuclear (CBRN), Consequence Management and Advisory Division (CMAD); EPA's National Homeland Security Research Center (NHSRC); EPA's Environmental Response Team (ERT); EPA's Region 4; the UF faculty and staff; and several contractors.

While this report discusses the results of the operational fumigation, it also provides guidance documents that could be used during a response at a later date. The plans used to govern the fumigation for this test site were revised based on the lessons learned (listed in Appendix A) at this site. Additionally, a field operational guidance document, detailing the use of MB for the fumigation of buildings, rooms, and sensitive items, was written for New York City. The revised plans and guidance are included in this report as attachments, and can be modified and used at other sites requiring MB fumigation. They include:

- Attachment 1: Health and Safety Plan (HASP)
- Attachment 2: Ambient Air Monitoring Plan (AAMP)
- Attachment 3: MB Field Operational Guidance to New York City

1.1 Background

In 2001, a series of letters containing *Ba* spores were mailed to various locations throughout the U.S. It was determined that initial and residual contamination from *Ba* spores was difficult to detect, identify, and decontaminate in an efficient and expedient manner. Additionally, significant costs were incurred during decontamination and clean-up efforts of buildings and equipment that were suspected of being contaminated. Comments from the Government Accountability Office (GAO) reports and congressional inquiries pointed out that sampling and decontamination methods were not standardized and/or validated; and that deficiencies were observed when attempts were made to locate and characterize *Ba* contamination (GAO Report - 06-756T, 2006). The GAO recommended standardizing and validating procedures that could be used to characterize biological agent contamination and increasing capacity to effectively decontaminate buildings and associated areas. The research covered by this report is focused on efficient decontamination using fumigation; specifically, operational aspects of MB fumigation to increase remediation capacity in preparation for a response to *Ba* incidents.

Sandia and Lawrence Livermore National Laboratories used the U.S. Department of Homeland Security (DHS), national planning scenario number two as a basis to produce a systems analysis report for a *Ba* wide-area release (IBRD, 2008). The resulting area of > 100 spores per square meter (m^2) deposition was 6 square miles, and the resulting area of 10-100 spores/m^2 deposition was 160 square miles in total. Based on a number of considerations as well as the current state-of-the-science, EPA and CDC (CDC-EPA, 2012) recommend that "no detection of viable spores" is the best practicable clearance goal. With this as the clearance goal, the entire area, 166 square miles would require remediation. This IBRD report estimated that it would take 15 to 18 years to complete the remediation using the current remediation capacity.

The authors of the IBRD report considered using vaporized hydrogen peroxide (VHP) and chlorine dioxide gas (ClO_2) to achieve building and surface decontamination. Bleach solutions or other liquid oxidants were also considered for the decontamination efforts in portions of buildings where the primary source of contamination was determined to be tracked in by humans or animals. The IBRD authors did not include MB as one of the fumigants even though the report highlighted several important gaps; one being the "limited resources for indoor fumigation."

Corrosion and discoloration of materials are associated with the use of the majority of current *Ba* remediation technologies. Even if the capacity of the current technologies is increased, the collateral damage caused during fumigation or liquid application could generate a significant volume of waste, thus increasing remediation time and cost. In the case of sensitive or historic infrastructure, corrosive (methods relying on oxidation) remediation techniques are not an option even if capacity is achieved. Several studies have been conducted to look at fumigant efficacy against *B. anthracis* and the corrosion caused by fumigants. The studies listed below highlight findings for MB.

- The U.S. EPA has conducted several studies looking at decontamination agent's material compatibility with electronics and items of historical value.
    - An unpublished U.S. EPA study[1] on historical materials examined the impact of ClO_2, VHP, ethylene oxide (EtO), and MB on several types of materials. This study provided insight into the risk for damage from a decontamination scenario using different fumigants. Based on this work, VHP, EtO, and MB can be considered the most compatible (of those fumigants and materials tested) with museum quality objects. MB would be a viable alternative for a whole-building decontamination scenario when materials such as books, documents and photographs are present.
    - In another study (U.S. EPA, 2012), personal computers were exposed to MB fumigation under the same conditions necessary to inactivate spore forming bacteria. The fumigant included 2% chloropicrin mixed in with the MB. The chloropicrin appeared to oxidize some components in the computer system.

[1] Point of Contact: Dr. Shannon Serre, ORD, EPA

- Laboratory studies by U.S. EPA (U.S. EPA, 2011) on seven different building materials found that MB fumigation was efficacious for the decontamination of *Ba* Ames (a virulent strain of *Ba* spores) on a broad range of indoor building materials tested.
- Corsi et al. (2007) concluded that MB does not engage appreciably in sorptive interactions with indoor materials, although some diffusion can occur into porous materials. Desorption of adsorbed MB from indoor materials appears to be rapid. It also appears that exposure of some building materials to elevated concentrations of MB leads to an increase in the off-gassing rate of carbonyls and several methylated aliphatic compounds. However, the absolute increases appear to be small and are likely not a major concern for either disinfection workers or those who reoccupy a building after a disinfection event.
- Juergensmeyer et al. (2007) established that a MB minimum effective dose of 80 mg/L was lethal to a concentration of 10^7 spores of *Ba,* specifically, nine different strains (including Ames and Sterne) on glass slides after a 48-hr exposure at 37 degrees Celsius (°C). In addition, at the same exposure conditions, 10 strains of *Bacillus anthracis* (ATCC 10, ATCC 937, ATCC 4728, ATCC 9660, ATCC 11966, ATCC 14187, AMES-1- RIID, AMES-RIID, ANR-1, and STERNE) were equally susceptible to MB and were not dependent upon virulence factors. The study showed that *B. atrophaeus* and *B. thuringiensis* were more resistant than *Ba* to MB when tested at similar conditions. All *B. thuringiensis* and *B. atrophaeus* spores tested showed a dose-dependent reduction in spore numbers, but they were not reduced below detection level by any MB concentrations tested. The authors concluded that MB has several advantages as a fumigant: First, because MB is a registered structural fumigant, personnel trained in its use are available nationally. Additional training in decontamination procedures would be minimal for these professionals. Second, decontamination is rapid, occurring within 48 hours. Extensive preparation of the contaminated item is not required, and all furnishings or other internal structures or items may remain in place. Third, MB leaves no residue, and is a noncorrosive alkylating agent that does not damage commodities (e.g., food supplies), furnishings, documents, or even sensitive electronic equipment.
- Weinberg et al. (2004b) conducted a MB field trial within a 30,000 cubic foot structure. Filter paper coupons containing 10^6 spores of one of three species, *Geobacillus stearothermophilus*, *B. atrophaeus* and *B. thuringiensis*, and stainless steel coupons with 10^6 spores of *B. atrophaeus* were placed in 50 locations within the structure. Fumigation was conducted using 312 mg/L of MB for 48 hr at 35.5 °C with overall mean RH of 76%. The results of the field trial found that only one location, a sealed refrigerator, contained viable spores of *B. atrophaeus* on a single coupon. It was noted that the performance of sensitive electronics and electronic media placed in the structure were unaffected by the MB fumigation.
- The *Bio-response Operational Testing and Evaluation (BOTE)* Project (U.S. EPA 2013) was a multi-agency effort designed to operationally test and evaluate, at the scale of a moderately sized building, a response to a *Ba* release from initial public health and law enforcement investigation through environmental remediation. The BOTE Project was

divided into two phases: a field-level decontamination assessment and an operational exercise. Phase 1 tested three decontamination methods on inactivating a *Ba* simulant, fumigation with hydrogen peroxide vapor, surface application of pH-adjusted bleach, and fumigation with chlorine dioxide gas. It was proposed that one of these three methods would be used during the Phase 2 exercise; however, because all three had already been evaluated during Phase 1, in an effort to expand our knowledge of potential response tools, a forth alternative, fumigation with methyl bromide gas, was selected for use during Phase 2. The fumigation process was successful; however, there were some technical difficulties that affected the outcome of the spore inactivation and the subsequent aeration process.

1.2 MB Usage and Properties

MB, also known as bromomethane, is a colorless, odorless (at low concentrations), and nonflammable gas and is classified as an alkyl bromide. MB is containerized as a liquid under modest pressure, approximately 2 atm. MB is used primarily as a pesticide to control insects, nematodes, weeds, pathogens, and rodents. MB was originally registered by EPA for various applications including: soil fumigation (injected into the soil before a crop was planted to effectively sterilize the soil); commodity treatment (used for post-harvest pest control); structural pest control (used to fumigate buildings for termites; and warehouses and food processing facilities for insects and rodents); and quarantine uses (used to treat exported and imported commodities such as logs, fresh fruits and vegetables).

MB fumigant concentrations and contact times vary with the commodity or structure being treated, the target pest, temperature, and RH. MB is an effective pesticide because it acts as a methylating agent that disrupts an organism's internal enzymatic protein chemistry. However, the production of MB was reduced (2005) under an international treaty called the Montreal Protocol, and by EPA under the Clean Air Act (CAA) (http://www.epa.gov/ozone/mbr/) due to its stratospheric ozone-depleting potential. Use now requires an exemption by the EPA under appropriate provisions in the CAA. MB is currently used in the U.S. only under these exemptions and is manufactured in the U.S. by Chemtura Corp. with label provisions developed by Great Lakes Corp. Allowable exemptions include: the Quarantine and Pre Shipment (QPS) exemption, to eliminate quarantine pests; and the Critical Use Exemption (CUE), designed for agricultural users with no technically- or economically-feasible alternatives. Under those exemptions there are approximately seven-million pounds of MB used annually in the U.S. In addition, there is a third allowable exemption "the Emergency Exemption" that is not well defined at this time.

Due to the need to find an effective fumigant or method to inactivate *Ba* spores, the EPA continues to research decontamination technologies, including MB at relatively low temperatures and RH levels (U.S. EPA, 2014).

Before phase-out began in 2005 as part of the Montreal Protocol, as an ozone-depleting substance, MB fumigation was widely used for 60 years against soil and structural pests. Currently, MB is still used for quarantine fumigations against pests that harbor in perishable commodities. Most major U.S. seaports, and some airports, have United States Department of

Agriculture (USDA) regulated facilities for MB fumigations of imported fruits and vegetables. These facilities have crews trained in MB fumigation using much of the same equipment and methods as used in structural fumigations. While the crews have the technical expertise to conduct lawful fumigations, only a small percentage of fumigation crews currently working in the industry meet the requirement to enter a biological agent remediation site. Requirements would include Occupational Safety and Health Administration (OSHA) Hazardous Waste Operations and Emergency Response (HAZWOPER) certification, medical clearance to wear respiratory protection, and the annual respiratory protection training (medical clearance, self-contained breathing apparatus [SCBA] use, and respirator training are already existing requirements for licensed fumigators). In addition, fumigation workers would need site-specific training with a focus on the hazards of *Ba* and on conducting their fumigation tasks while in level-C, most likely including power air purifying respirators. Initial HAZWOPER technician training is a one-time 24-hour event with subsequent 8-hour refresher training required annually. To overcome this deficiency, fumigation industry workers without the required HAZWOPER training could be prepared with minimal training to meet these requirements as needed for emergency response remediation work.

The structural fumigation industry (mostly non-MB usage) is located in Florida, the Gulf Coast, the Southwest, and Hawaii. The quarantine fumigation industry (MB usage) in mainly located at large sea ports and airports where international cargo is imported. In a national emergency involving the release of *Ba*, this industry could potentially be used to increase our remediation capacity; especially when the building material and building contents are deemed incompatible with other remediation technologies.

MB penetrates quickly and deeply into sorptive materials at normal atmospheric pressure. Also, at the end of a fumigation treatment, its vapors dissipate rapidly from those materials (Corsi et al., 2007). Another important property of MB is the fact that freshly harvested produce has been shown to be tolerant to this gas in insecticidal treatments, offering to potential outdoor applications. MB is nonflammable and non-explosive under ordinary circumstances and may be used without special precautions against fire.

In the absence of oxygen, liquid-phase MB reacts with aluminum to form methyl aluminum bromide. Methyl aluminum bromide ignites spontaneously in the presence of oxygen. **Liquid MB should never be stored in cylinders containing any appreciable amount of the metal aluminum and aluminum tubing should not be used for application of the liquid phase of the fumigant.**

The chemical properties of MB are summarized in Table 1 below.

Table 1. MB Chemical Properties

Chemical formula	CH_3Br
Boiling point	3.6 °C
Freezing point	-93 °C
Molecular weight	94.95
Specific gravity gas (air=1)	3.27 at 0 °C

Liquid (water at 4 °C=1)	1.732 at 0 °C
Vapor Pressure	1400 mmHg at 20°C
Latent heat of vaporization	61.52 calories per gram (cal/g)
Flammability limits in air	Flammable between 10-15% (some say 20%) in air
Solubility in water	1.34 g/100 ml at 25 °C
Odor	Odorless at low concentrations; strong musty or sickly sweet odor at high concentrations (greater than 1,000 ppm)
Pertinent chemical properties (Liquid phase only)	Powerful solvent of organic materials, especially natural rubber. Reacts with aluminum and its alloys to form methylated aluminum compounds that are spontaneously flammable in air (see text below). Reacts with zinc, magnesium, tin, and iron surfaces in the presence of impurities such as water or alcohol. Avoid the presence of acetylenic compounds, ammonia, dimethylsulfoxide, ethylene oxide, oxidizers, and hot metal surfaces. Attachment 1 provides further details regarding MB.

1.3 Health and Safety

With all fumigants, human exposure is a concern that should be addressed and managed because of their toxic nature and inhalation hazard. MB is no exception. MB is a toxic chemical. Because MB dissipates so rapidly to the atmosphere, it is most dangerous at the actual fumigation site itself. Human exposure to high concentrations of MB can result in central nervous system and respiratory system failure, as well as specific and severe deleterious reactions affecting the lungs, eyes, skin, kidneys, and liver.

The compound has a history of industrial use, and it is fairly well characterized in terms of human toxicity, including recommended and regulatory occupational exposure limits (OEL). For the purposes of this study, a detailed HASP was developed that integrated personnel and area monitoring, emergency response, medical monitoring, personal protective equipment (PPE) requirements, clearance thresholds, and more.

Although this study was a research project, the fumigation site was managed as if it were an emergency response site with the designation of an Exclusion Zone (EZ) or “hot zone”, a Contaminant Reduction Zone (CRZ) or “warm zone”, and a Support Zone (SZ) or “cold zone. The three zones were delineated based upon the most conservative airborne OEL provided by the OSHA, the National Institute for Occupational Safety and Health (NIOSH), and the American Conference of Governmental Industrial Hygienists (ACGIH). The ACGIH threshold limit value (TLV) is 1 ppm as an 8-hour time-weighted average (TWA) and the OSHA permissible exposure limit (PEL) is 20 ppm as a ceiling value that cannot be exceeded in any part of the workday. The NIOSH immediately dangerous to life or health (IDLH) value is listed as 250 ppm. It should be noted that there is no NIOSH recommended exposure limit (REL), as NIOSH considers MB a potential occupational carcinogen. Other organizations, such as the International Agency for Research on Cancer (1986), the National Toxicology Program (1992), and the EPA (1988) do not classify MB as a potential human carcinogen.

In addition to inhalation exposure limits, the OELs annotate a skin notation, which suggests potential adverse effects to the skin, and/or absorption through the skin. The reports of Jordi (1953) and Hezemans-Boer (1988) suggest that sweating increases vulnerability to skin absorption in humans. Yamomoto (2000) studied cutaneous exposure of rats to MB, but it is not clear whether the exposure was to liquid or vapor. They found an immediate rise in plasma bromide ion, with a plasma clearance half-life of 5.0 – 6.5 days.

For purposes of this MB fumigation study, zones were established as follows: EZ > 0.5 ppm; CRZ > non-detect and < 0.5 ppm; and SZ = non-detect. Wind directional flags were used throughout the fumigation, and the SZ was maintained upwind from the fumigation. Personal protective equipment including SCBAs and foot and hand protection were prescribed based on work task(s). SCBAs were required for entry into an area with airborne concentrations consistently exceeding the action level (a level of MB concentration that requires mitigative actions), 0.5 ppm. Two Certified Industrial Hygienists (American Board of Industrial Hygiene) served as the site safety officers (SOs) and provided 24-hour oversight of the project during all fumigation activities. Personal breathing zone samples were collected on EPA and contract personnel by the SOs during tasks identified as having potential for MB exposure. These tasks included coupon extraction and carbon scrubber operations conducted during the aeration of the test house.

The HASP restricted entry into the test house from the time fumigation began until the fumigation was complete and airborne concentrations were measured to be below 5 parts per million (ppm). Workers in SCBAs could enter the house when the MB concentration was below 5 ppm and could enter without SCBAs when the MB concentration fell below the action level, 0.5 ppm. When dispensing MB from cylinders, workers wore loose fitting clothing, as required by the MB labeling, to reduce the risk of trapping liquid MB under clothing next to the skin. Engineering controls, work practices, and required PPE were all detailed in the site-specific HASP.

The risk of exposure to MB, without sufficient warning, is significant because MB is a colorless and odorless gas (odorless at working concentrations). To address this significant risk, a detailed AAMP for MB monitoring and HASP outlining measures to protect workers and adjacent building occupants was followed.

After completion of the test and review of the lessons learned, a revised HASP (Attachment 1) was created to serve as an example HASP that can be modified and used at other sites requiring MB fumigation.

1.4 Study Objectives

The overall goal of this test was to conduct and evaluate the operational aspects and the efficacy of MB fumigation for the inactivation of a nonpathogenic *Ba* surrogate for pathogenic *Ba* spores in a single-story ranch-style house. The following five objectives were developed in order to reach this overarching stated goal:

1.4.1 Objective 1

To develop a Quality Assurance Project Plan (QAPP) for the fumigation of the University of Florida, Hurricane House in Davie, FL using MB for the inactivation of the chosen non-pathogenic surrogate spores. This study included the development of a Remediation Action Plan (RAP); a site-specific HASP; Sampling and Analysis Plan (SAP), as part of the QAPP; and an AAMP, to govern this site-specific MB fumigation. With minor changes, these site-specific plans (i.e., RAP, HASP, SAP, and AAMP) could be easily modified and used at other sites for MB fumigation of *Ba*.

1.4.2 Objective 2

To conduct the fumigation process safely, economically, and effectively. To monitor and maintain MB concentrations, temperature and relative humidity (RH) during the testing to assure dose requirements were reached inside the house during fumigation; ≥ 212 mg/l, ≥ 27 °C, and ≥ 75%, respectively, during a 48-hour period. Furthermore, MB concentration, temperature, and RH will be monitored from outside the house before, during, and after the same 48-hour period.

1.4.3 Objective 3

To evaluate the efficacy of the fumigation by measuring the post-fumigation viability of surrogate spores. This was accomplished by inoculating *Ba* Sterne onto coupons (wood and glass) and placing them in 22 locations throughout the house prior to fumigation, followed by analysis of viability.

1.4.4 Objective 4

To operationalize and evaluate the effectiveness of activated carbon for the capture of the MB fumigant during the aeration portion of the fumigation cycle. In addition, during aeration of the house, to monitor MB breakthrough status of the activated carbon and provide an estimate of house re-entry time.

1.4.5 Objective 5

To monitor the effectiveness of MB containment and provide for the health and safety of workers during the entire fumigation process.

The HASP, RAP, and AAMP provided detailed procedures for air monitoring and for handling elevated levels (>0.5 ppm) of MB in the ambient air during all aspects of the fumigation. Achieving these objectives will result in greater resiliency and capacity to respond to and recover from a *Ba* release or other biological incident.

2 Materials and Methods

2.1 Facility

The study building was the University of Florida "Hurricane Resistant Model Home" (house) (Figures 1, 2). The house encompassed 1,444 cubic meters (m^3) (51,000 cubic feet [ft^3]), including the exterior volume contained below the edge of the eaves. Constructed in 2005, the ranch-style house is used for teaching and meeting functions and contains two large open meeting areas, an office, a kitchen (with refrigerator and oven), two restrooms, two utility closets, an HVAC room, and a storage/computer room. The house also contains two desktop computers, a computer router, two LED monitors, and an LCD projector (Figure 3). The house is on the campus of the Fort Lauderdale Research and Education Center, Institute of Food and Agricultural Sciences, University of Florida, 3205 College Avenue, Davie, FL 33314 (26.08343, -80.24115, two meter elev.). Adjacent to the study house were two buildings that served as student housing. As part of the health and safety protocols, these two buildings were evacuated during the fumigation. A diagram of the campus grounds is shown in Figure 4. As an additional safety precaution, a nine meter (30 ft) radius away from the perimeter of the house was cordoned off to non-authorized personnel.

Figure 1. The House used for this Study on the Campus of the Fort Lauderdale Research and Education Center, University of Florida, Davie, FL

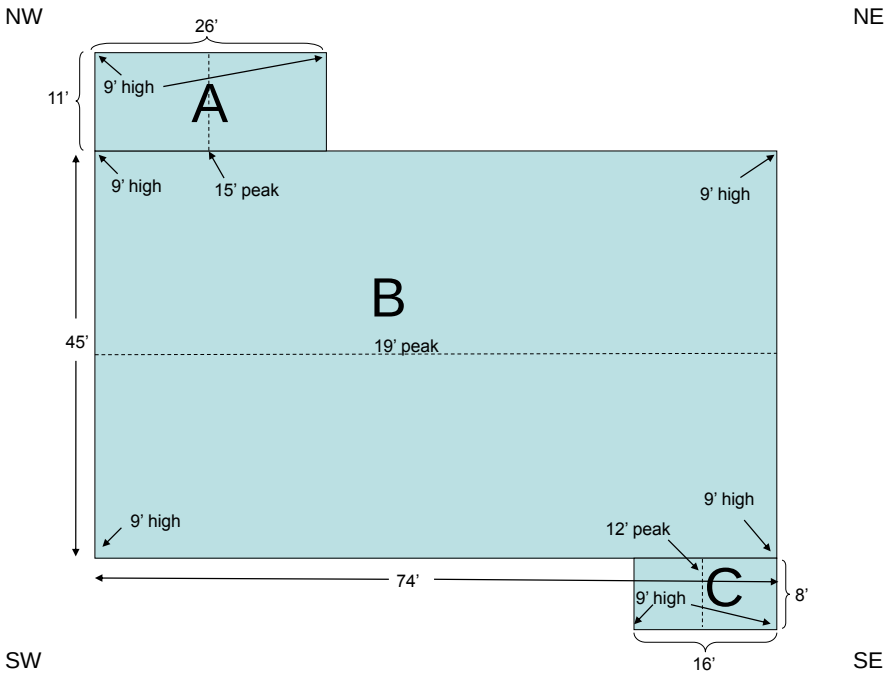


Figure 2. External Dimensions of House used in this Study.

A) Back Porch, B) Main Structure, C) Front Porch

Figure 3. The Electronics that Remained in the House during Fumigation

Figure 4. Area Around the House

2.2 Sealing the House

In preparation for sealing the house, the turfgrass surrounding the study house was mowed and edged with a string trimmer to a height of 3 cm. Fine sand was then applied in areas around the perimeter where foundation drop-offs or uneven or porous surfaces were found. Next, a 1.8-

meter-wide tarpaulin (tarp) apron made of 6-mil high diffusion-resistant polyethylene vinyl alcohol (EVOH) with polyester scrim reinforcement (GeoCHEM Inc., Renton, WA) was taped to the house at ground level around the entire perimeter of the house using 8-cm-wide resilient tape (Shurtape, Cardinal Pro. Prod., Anaheim, CA). A narrow bead of silicone sealer was also applied over the edge of the tape where it adhered to the house foundation (Figure 5). The EVOH tarp has a white surface on one side and a black surface on the other side. For the apron installation, the tarp was used white side down. Three 80 x 100 ft sections of EVOH tarps were hoisted onto the roof and arranged to cover the entire house, black side out, by the tenting contractor (Dead Bug Edwards, Fort Lauderdale, FL). The sections were joined by overlapping and rolling adjacent edges together and binding them with plastic-tipped, metal spring fumigation clamps. As the house was covered, horizontal "skirts" were dropped from the roof onto the apron (Figure 6). The skirt and apron were held down on the ground directly below the roofline with overlapping 40-lb sand "snakes" bags. The edges of the skirt and apron were then tightly rolled and secured with clamps (Figure 7). To add physical strength and protect the first tarp in the case of strong winds, a second commercial fumigation tarp, vinyl-coated nylon fabric, 12 ounces per square yard, white in color (Figure 8), was placed over the first tarp in the same manner as the first and was secured to the ground atop the skirt and apron with additional overlapping sand snakes (Figure 9).

Figure 5. Attachment of Tarp Apron to Foundation of House with Tape and Caulk

Figure 6. View of the Skirt of EVOH Tarp Dropped to the Apron on the Ground

Figure 7. To Seal, the Skirt and Tarp Covering the House Were Rolled and Clamped at Edges and Weighed Down with Sand Snakes

Figure 8. Second Tarp (White) Positioned Over Black EVOH Tarp

Figure 9. In Preparation to Fumigate, the House was Sealed with Two Tarps

The tarp seal around the house was opened at two skirt seams to accommodate the 24-inch diameter, fresh-air inlet port (Figure 10) and 24-inch diameter, exhaust port (Figure 11) for the aeration procedure. Both the inlet port and the exhaust port were sealed with metal lids during the fumigation. The ground seal was also opened between the skirt and apron of the first tarp and the second tarp to allow the insertion of 4-inch diameter, polyvinyl chloride (PVC) pipes that were used as conduits for two MB introduction or "shooting" hoses (3/4" braided chemical resistant, high temperature [149 °C rating], and high pressure [> 200 pounds per square inch rating]), monitoring lines (6.4 millimeter outer diameter, nylon), and a test coupon slide designed to extract test coupons during intermediate phases of the fumigation (Figure 12). The two MB shooting hoses were extended into the tested house with a similar inside diameter polyethylene tubing connected together with compression fittings. These hoses were clamped and taped into the bottom of a 5 gallon plastic bucket placed in the entry way of the tested house (Figure 13). The bucket also contained a concrete block as weight for stability. The bucket was used as the release point for the fumigation inside the tested, house and to protect the house floor. As MB gas flows out of the shooting hoses, the bucket collects oils, rust, or other non-volatile contaminants that might be present in the cylinders. After the shooting and monitoring lines were routed through two pipes, any voids in the PVC pipe and pipe chases were filled and sealed with expanding polyurethane foam (Figure 14). The test coupon slide (PVC-pipe construction) was sealed at its exterior terminus with a threaded PVC cap.

Figure 10. Fresh-Air Inlet Port in Open Position (Closed during Fumigation)

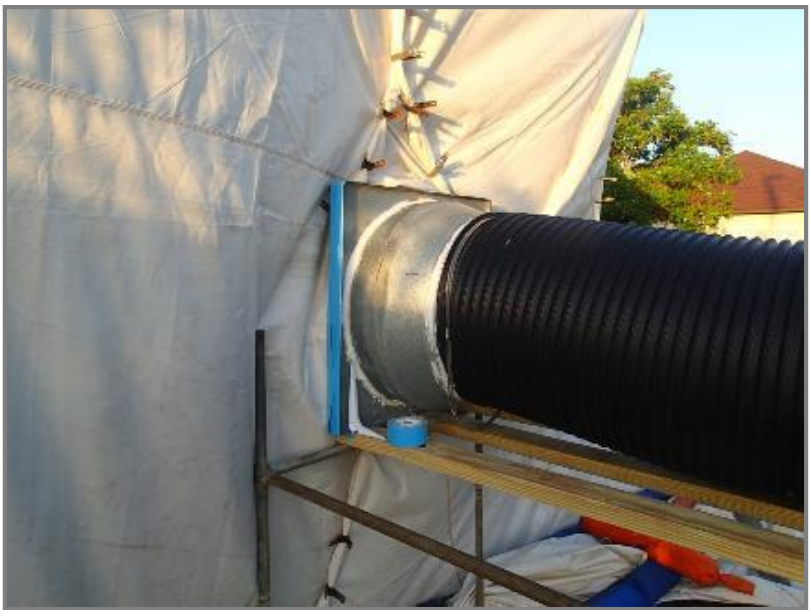


Figure 11. Flange of Carbon Scrubber Exhaust Port Joined to Tarp at a Seam

Figure 12. Monitoring Lines, Shooting Lines and Coupon Slide Inserted Between the Skirt and Apron (View from Inside House)

Figure 13. Bucket Release Point of Fumigant Inside House with Mixing Fan

Figure 14. PVC Pipe Voids and Pipe Chases Filled with Expanding Polyurethane Foam.

Note: Threaded Cap on Coupon Slide (White PVC Pipe) in Center of Photograph

(Outside House View)

2.3 Circulation Fans, Heaters and Humidifiers

Interior preparation of the house included the placement of seven 3,000 cubic feet per minute (cfm) fans (Figure 13), sixteen 1-gallon capacity warm steam vaporizers (Figures 15 & 16) (Walgreens Brand Model 21413ktc, Springfield, IL), and four 1,500 watt radiant heaters (Delonghi, Model EW7707CM, Woodridge, N.J.) (Figures 15 &16). The fans ran continuously during the fumigation (including during scrubbing and aeration) to maintain temperature and RH equilibrium throughout the house and to help disperse the MB gas when it was introduced into the house. The power supply for the radiant heaters and steam vaporizers were extended with two extension cords each and routed outside so they could be powered on or off as needed to maintain temperature and RH, 27 °C and 75%, respectively. The day before fumigating the house, the air conditioning system was turned off and the 16 steam vaporizers were turned on to increase the humidity of the materials within the house. The steam vaporizers were refilled prior to sealing the house and just before fumigation.

It is important to note that the contents within a volume to be fumigated should be factored into the fumigation decision process. When determining a decontamination approach, consideration must be given to the contents (e.g., paper, foam, water, fabrics, concrete, galvanized metal, etc.) as they may adversely impact the efficacy of the fumigation. Specific contents, when found in significant quantity, may act as sinks for fumigants, water vapor (humidity), and/or heat. Fumigant adsorption may be followed by latent desorption (off-gassing) for extended periods of time following the initial fumigation. Large amounts of paper, for example, may need to be removed or may need to be pre-humidified before fumigation; and large amounts of foam, may act as a sink for fumigant, requiring the foam to be removed or additional fumigant used to overcome the loss of fumigant to the foam. The interaction of the contents with the fumigant and fumigation parameters will dictate what actions may be needed; however, interactions are not always known in advance and fumigation parameters must be monitored during the fumigation to assure the parameters necessary for an efficacious decontamination are met.

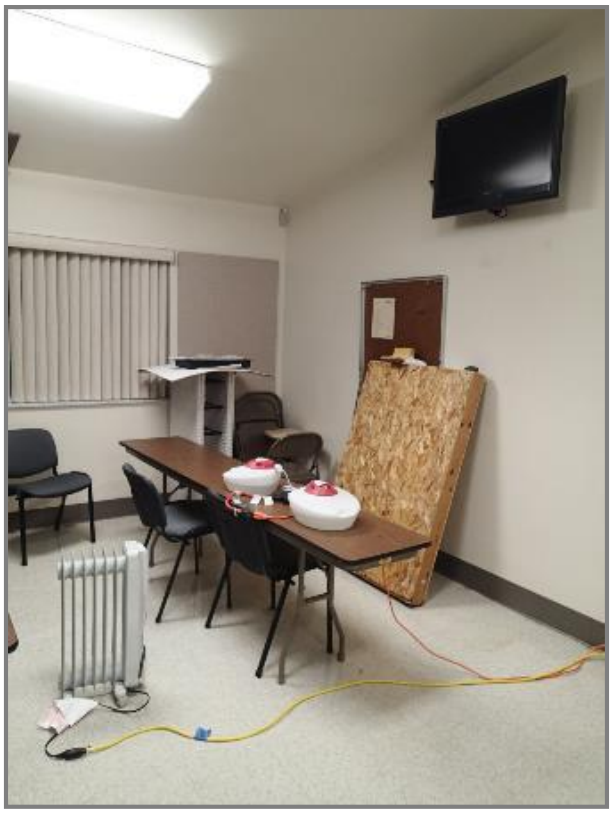


Figure 15. Radiant Heater and Two Steam Vaporizers in the House

(Fans not Shown)

All cabinets, appliances, interior doors, and two attic access panels were opened to aid reaching concentration, temperature and RH equilibrium. Exterior doors and windows were open in the large classroom side of the house but closed on the office side of the house where the scrubber duct was attached. This arrangement was used to direct airflow during aeration of the house: fresh air coming into one side of the house while exiting out the other side to the scrubber. All food was removed from the house, but everything else was left in place (furniture, two bed mattresses, telephones, computers, printers, televisions, tables, chairs, upholstered chairs and couch, carpet, flooring, lamps, HVAC system, books, paper, window treatments). The house was completely sealed on December 7 and 8, 2013.

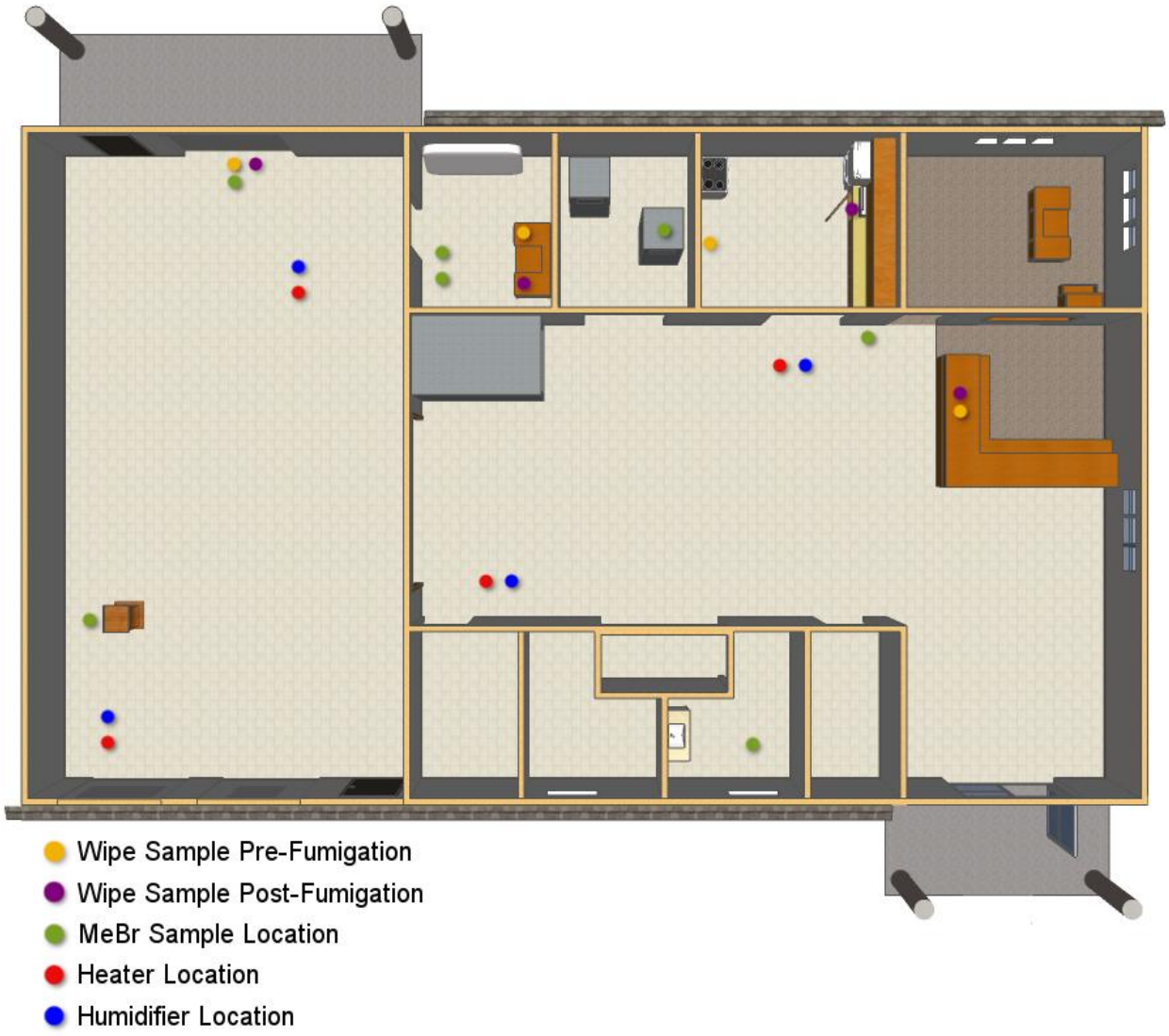


Figure 16. Schematic of House Showing Locations of Heater, Humidifiers, and MB Sampling Lines

2.4 Temperature and Relative Humidity Monitoring

Temperature and RH inside the house, were monitored during the fumigation, including the aeration phase, using a HOBO temperature and RH monitoring system (Model ZW-03, Onset Computer Corporation, Bourne, MA 02532). The system included 4 wireless sensor nodes spaced throughout the house and a router, which was placed on the front entryway under the tarp. The wireless system transmitted real-time data to the receiving station that was located approximately 100 feet from the house. Real-time temperature and RH data were collected and displayed on a laptop computer using HOBOware Pro software (Onset Computer Corporation, Bourne, MA 02532). These data were used to determine if heat and/or moisture needed to be added. In addition to the 4 wireless sensors, HOBO temperature and RH loggers (Model U10, Onset Computer Corporation, Bourne, MA 02532) were placed adjacent to 21 of the 22 coupon locations inside the house.

2.5 Coupon Preparation

A *Ba* surrogate for this study was selected based on a series of laboratory tests using several spore candidates; non-virulent strains *Geobacillus stearothermophilus*, *Ba* NNR1Δ1, and *Ba* Sterne. Spores of *Ba* Sterne 34F2, the vaccine strain (strain obtained from Colorado Serum Co., Denver, CO), were selected as surrogates for fully-virulent *Ba* spores. Spore production procedures were conducted at Yakibou Labs, Inc. (Apex, NC), according to proprietary methods.

Coupon material type was selected based on a series of laboratory tests (U.S. EPA, 2014) completed prior to this study using several material type candidates including glass, ceiling tile, carpet, wallboard paper, wood, and concrete. Two coupon material types (Figure 17, B and C) were selected for preparation of customized biological indicators (BIs); glass (premium pre-cleaned microscope slides, VWR International, Cat# 48300-047, Radnor, PA) and wood (Maple discs, 1.43 cm dia., 0.32 cm thickness, part# DIS-050, American Woodcrafters Supply Co., Riceville, IA). Glass and wood were chosen because studies have shown these materials were most resistant to spore deactivation with MB. Glass was cut into coupons (approximately 15 mm by 18 mm), washed in alkaline detergent to remove grime and grease, rinsed until no residue remained, dried at 125 – 150 °C, and sterilized by Yakibou, Inc. (Apex, NC) by steam autoclave (1 hour, 121 °C, 103 kPa, method of procedure [MOP] 6570). Wooden coupons were sterilized using ethylene oxide.

After sterilization, test and positive control coupons were inoculated using a liquid inoculation proprietary protocol (Yakibou, Inc.) with a target final spore inoculum of 2.0 to 5.0 × 10^6 spores (as determined by enumeration of colony forming units (CFU) per volume of inoculum) per coupon. Negative control coupons and field blank coupons, although not guaranteed to be sterile following packaging, remained un-inoculated. After inoculation, coupons were allowed to dry at room temperature on a bench top, and subsequently packaged into custom-sized Tyvek® pouches (Figure 17, A). The pouches were heat-sealed to prevent infiltration or exfiltration of spores or particulate contaminants, thereby preventing escape of the spores and maintaining the integrity of the BIs from the surrounding environment. Tyvek® pouches were pre-labeled with an identifier unique to each product type.

Pre-test and post-test determinations of BI population densities were performed at EPA, NHSRC, Research Triangle Park (RTP) Microbiology Laboratory (Table 2), according to MOPs 6535a, 6565, and 6566. These tests were conducted to determine the spore population on coupons prior to testing and then after fumigation (non-exposed coupons). Spores were extracted from the coupons, ten-fold serially-diluted, and then plated onto tryptic soy agar (TSA) plates. Following incubation at 35°C for 18-24 hours, the resulting CFUs were enumerated. The CFU abundance was used to estimate the total spore abundance on the coupons. Triplicate samples of each material type were analyzed for population density before and after the field test. In addition, ten replicate of stainless steel coupons (Figure 17, B), inoculated by Yakibou, Inc. at the same time as the glass and wood coupons, were analyzed for population densities, before and after the field test. These stainless steel coupons were expected to yield more accurate and repeatable

estimates of pre- and post-test viable spore population densities than glass or wood (Calfee, 2011), as recovery of spores from stainless steel surfaces is highly efficient.

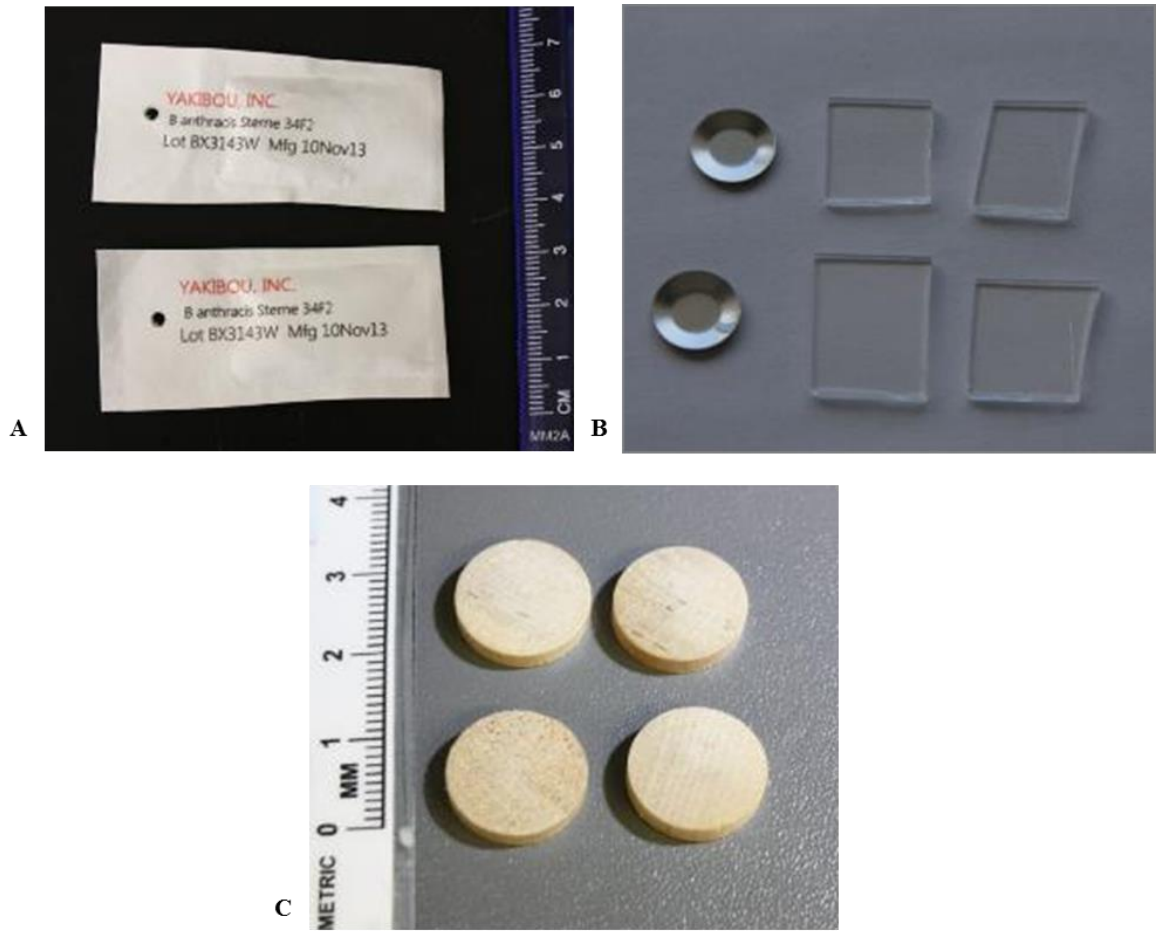


Figure 17. (A) Tyvek® BI Envelope, "BX3143W", Label Indicating Inoculated Wooden Coupons are Inside (B) Glass and Stainless Steel BI Coupons (C) Wooden Coupons

Table 2. Pre-Test and Post-Test BI Population Densities Samples

Sample Type	Location	Purpose	Frequency	Quantity	Analysis
Coupon enumeration for pre- and post-fumigation QC	EPA Microbiology Laboratory	To determine spore population densities on coupons pre- and post-test	one set each material before test and one set after test	32 total: 10 stainless steel 3 glass 3 wood	Enumeration

2.6 Analysis of Test Coupons

Two types of test coupons were utilized during the test to evaluate the efficacy of the MB fumigation (Table 3). These included: (1) BIs deployed throughout the house to qualitatively assess fumigant efficacy spatially; and (2) collocated coupons positioned inside the house (at the extraction port) and collected at specified time intervals to quantitatively assess fumigant efficacy temporally (Figure 12 & 14).

Table 3. Test Coupon Samples used to Evaluate the Efficacy of MB Fumigation

Sample Type	Location	Purpose	Frequency	Quantity	Analysis
Test BIs	22 locations inside the fumigated house	To determine the presence of viable spores after fumigation	Once per test	174 total: 87 wood 87 glass	Qualitative (growth, no growth)
Temporal Progression Coupons	Inside the fumigated house at extraction port	To determine fumigation efficacy as a function of time	One set of samples at 16, 24, 32, and 40 hrs. (four sets total)	48 total: 6 wood/set 6 glass/set	Enumeration

Four types of control BIs were utilized during the tests; procedural blank BIs, positive control BIs, negative control BIs, and lab-sterilized negative control BIs (Table 4). Procedural blank BIs were not inoculated but were collocated with test BIs during the fumigation and were used to determine the extent of cross-contamination from sample to sample during collection. Positive control BIs were inoculated in the same manner as test BIs, but were not exposed to MB. Positive control BIs traveled to the test venue, but remained in the sample shipment cooler for the duration of the test. Negative control BIs were not inoculated, but were packaged in the same manner as test BIs, traveled to the testing venue, remained in the sample shipment cooler, and were not exposed to MB. Since procedures required for packaging BIs into envelopes are not strictly aseptic, these BIs were not guaranteed to be sterile. Accordingly, positive growth results from these controls should not be interpreted to indicate a compromise in sample integrity through contamination. Lastly, lab-sterilized negative control BIs were BIs received from Yakibou, Inc. and autoclaved (1 hour gravity cycle) upon arrival at the NHSRC RTP Microbiology Lab to sterilize. These BIs were used to assess the handling technique of the laboratory personnel during culturing procedures. Growth from these BIs would indicate a compromise of sample integrity through contamination within the laboratory.

Table 4. Control BI Samples Utilized During the Test

Sample Type	Location	Purpose	Frequency	Quantity	Analysis
Procedural Blank BIs for Test BIs	Same 22 locations as Test BIs	To go through fumigation and determine extent of cross-contamination	Once per test	44 total: 1 wood/ 1 glass/ location	Qualitative (growth, no growth)
Procedural Blank BIs for Temporal Progression BIs	Same location as Temporal Progression BIs	To go through fumigation and determine extent of cross-contamination	One set of samples at 16, 24, 32, and 40 hrs. (four sets total)	16 Total: 2 wood/ 2 glass/ set	Enumeration
Positive Control BIs	BIs went to the site but remained in coolers, did not get fumigated	To determine the presence or non-presence of viable spores on non-fumigated BIs	Once per test	48 total: 24 wood 24 glass	Qualitative (growth, no growth)
Negative Control BIs	BIs went to the site but remained in coolers, did not get fumigated	To determine the presence or non-presence of viable spores on non-fumigated BIs	Once per test	48 total: 24 wood 24 glass	Qualitative (growth, no growth)
Lab Sterilized (Negative Control) BIs	Lab negative control (EPA Microbiology Lab only)	To demonstrate sterility of BIs and extraction materials/methods.	Per analysis of test samples	6 total: 3 wood 3 glass	Qualitative (growth, no growth)

2.7 Spatial Assessment of Efficacy (Qualitative Test)

Four duplicate BIs of each type, wood and glass, along with one procedural blank of each coupon type (non-inoculated wood and glass BIs) were positioned at 22 locations (Figure 18) throughout the house prior to fumigation. Coupon locations included placement inside a desk drawer (Location A), inside file cabinets (C, L), in a kitchen cabinet (E), in an oven (F), inside the HVAC return duct (G), inside the metal hurricane shelter (I), in the attic (J), under insulation in the attic (K), on porches (P,Q,V), near a drain in a sink (R), in restrooms (S,T), and in a utility closet (U). These BIs remained within the house during fumigation, and were retrieved after MB air concentrations within the house had subsided. Once removed from the house, the BIs were then aired out to allow MB to escape, cold packed, and transported to the NHSRC RTP Microbiology Lab where they were analyzed qualitatively for surviving spores (MOP 6566). Briefly, in a biological safety cabinet, BI coupons were carefully and aseptically removed from Tyvek® envelopes and placed into bacterial growth media (10 ml of TSA). Culture tubes (18 mm x 150

mm sterile borosilicate glass tubes for glass coupons or 25 mm by 150 mm sterile Pyrex® tubes for wood coupons) containing broth and BI coupon were then incubated at 35°C for 7 days. Periodically (on days 1, 3, and 7), the turbidity of the tubes was observed and the results recorded. Turbid media indicated the presence of bacterial growth, and hence incomplete decontamination. Representative turbid and lucid culture tubes are depicted in Figure 19.

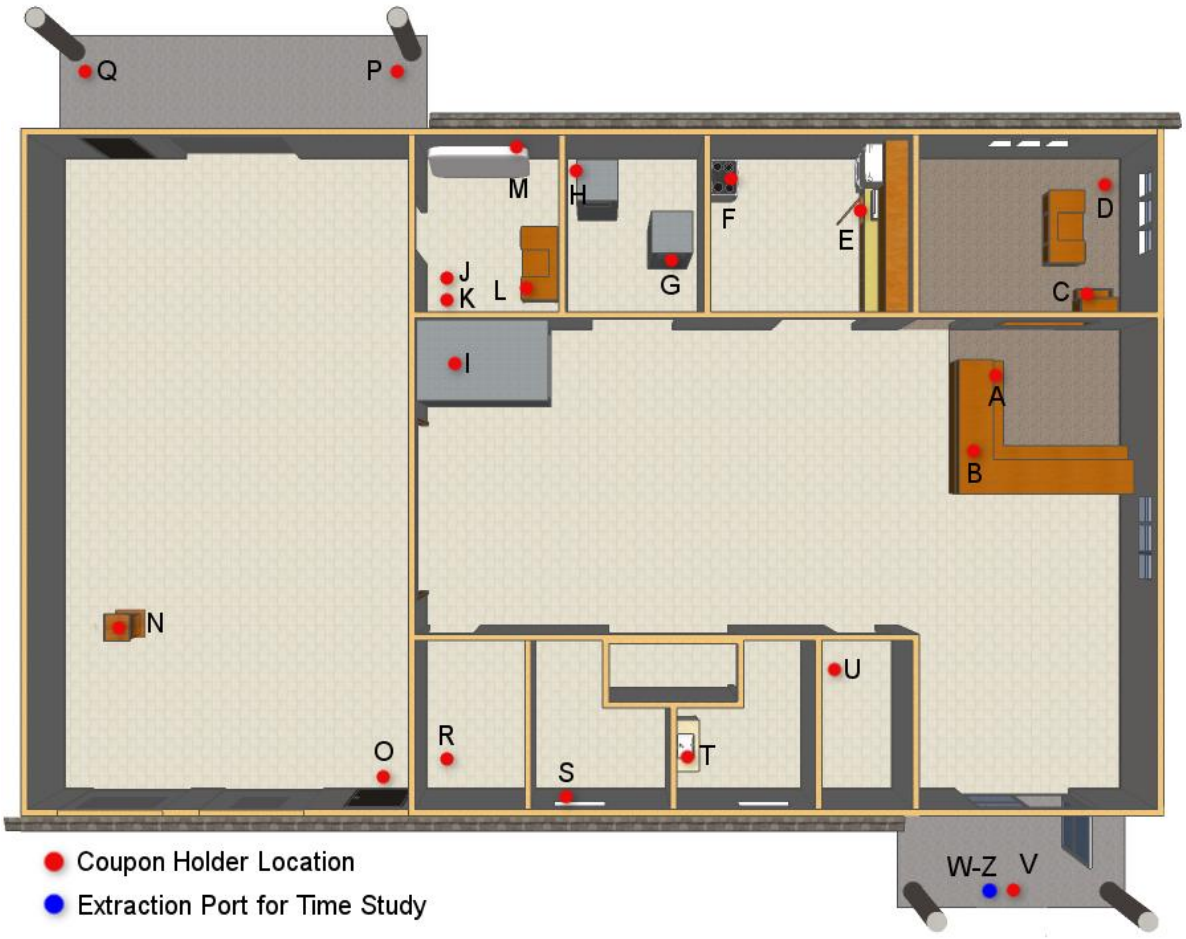


Figure 18. Test House, Location of Test BIs (22 red dots), And Temporal Progression Coupons (blue dot)

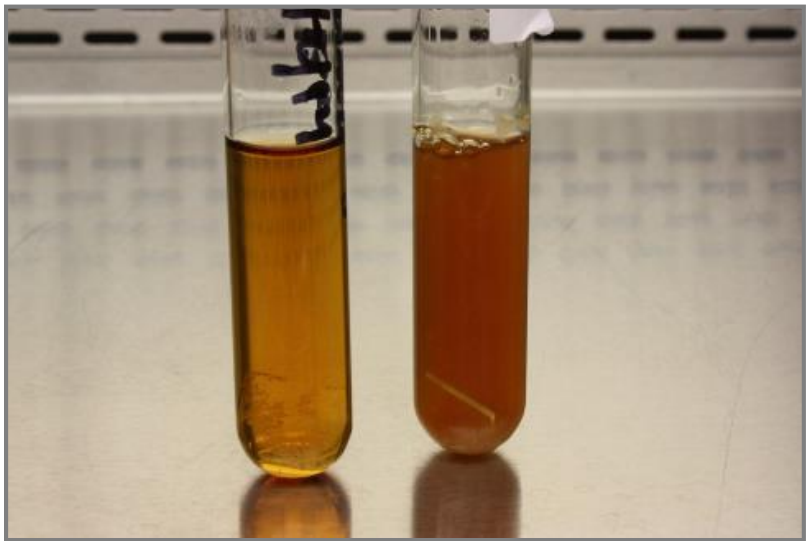


Figure 19. Photograph of representative culture tubes:
Left: lucid = growth negative
Right: turbid = growth positive

2.8 Temporal Assessment of Efficacy (Quantitative Test)

In order to assess fumigation efficacy as a function of time, six replicates of each coupon type (wood and glass) along with two procedural blanks of each coupon type (non-inoculated wood and glass coupons) were retrieved from the tented enclosure at the 16th, 24th, 32nd, and 40th hour into the fumigation. All coupons for a particular time-point were collocated at the coupon slide on a stainless steel spring, and retrieved from the house by pulling on a metal wire attached to the spring (Figures 12 & 14). Samples were allowed to off gas MB then they were packaged (with cold packs) and transported to RTP NHSRC EPA Microbiology Laboratory for extraction and analysis. Using aseptic technique in the laboratory, the coupons were placed into 18 mm x 150 mm sterile borosilicate glass tubes (glass coupons) or 25 mm by 150 mm sterile Pyrex® tubes (wood coupons) each containing 10 ml phosphate buffered saline with Tween20 (PBST). Each vial was then sonicated for 10 minutes at 42 kilohertz and 135 Watts (MOP 6566). Then tubes were vortexed two-continuous minutes to further dislodge spores from the glass, wood or metal coupon. Immediately before dilution or plating, each vial was briefly re-vortexed to homogenize the sample. The resulting extracts were subjected to five sequential 10-fold serial dilutions (MOP 6535a), and 0.1 ml of each dilution was inoculated onto TSA plates, spread with sterile beads (MOP 6555), and incubated at 35 °± 2 °C for 18-24 hours. Following incubation, CFUs were enumerated manually. A photograph depicting representative dilution plates is shown in Figure 20.

Figure 20. Representative Dilution Plates Containing *Ba* Sterne Colonies Recovered from Biological Indicators

2.9 Pre and Post Sponge Stick Sampling

The surrogate spores remained on the test coupons and inside Tyvek® envelops throughout the study (i.e., during transportation to the site; distribution, fumigation, and collection processes in the house; and transportation back to the lab). However, sponge wipe samples were collected on surfaces in the test house before test BIs were deployed to gain an understanding of background contamination within the house and after test coupons were retrieved at the end of the fumigation aeration cycle to determine if the test organism escaped the BI Tyvek® envelopes, or if other contamination was present on surfaces following the fumigation. Wipe sampling was conducted according to MOP 3144 and based on CDC protocols (CDC 2012, http://www.cdc.gov/niosh/topics/emres/surface-sampling-bacillus-anthracis.html). A total of eight wipe samples were taken, four before and four after the fumigation (see Figure 16 for sample locations).

2.10 Activated Carbon Scrubber

The activated carbon system was leased from TIGG Corporation (Oakdale, PA) and arrived via commercial carrier on the morning of Thursday, December 5, 2013. The system was unloaded from the truck and staged for subsequent placement and installation. The scrubber system consisted of two scrubber vessels (N5000 PDB, TIGG, Oakdale, PA), each containing approximately 5,500 pounds of activated carbon (TIGG 5CC 0408); one centrifugal blower with damper (Model 40-2800, Northern Blower, Manitoba, CA); 75-feet of 20-inch inner-diameter (ID) flexible rubber ducting with spring steel reinforced helix; 26-kilowatt Generator (Model DB-0501I, Whisperwatt, Los Angeles, CA); exhaust stack (7-inch x 20-inch ID); various galvanized metal joint fittings; and a galvanized slide gate valve.

The inlet to the scrubber system was connected to the office-room window (Figure 11) located on the northeastern side of the house. The window was removed and a 4-feet x 24-inch ID galvanized duct extension was used to penetrate inside the house and connect to the gate valve,

with the balance of the window space blocked with cardboard held in place with duct tape. Ten feet of the flex duct were connected on the outlet side of the gate valve to an 8-foot section of 20-inch ID straight galvanized duct. This straight section was used to perform flow measurements as described in Section 2.10.1. Following the straight section, ten feet of the flex duct were used to connect to the inlet of the first activated carbon vessel. Twenty-five feet of the rubber flex duct was used to connect from the outlet of the 1st vessel to the inlet of the blower that was positioned ten feet from the vessel. Ten feet of flex duct were used to connect the outlet of the blower to the inlet of the second carbon vessel. After traveling through both vessels, the scrubbed gas would be exhausted to the atmosphere through a 7-foot stack located on top of the second carbon vessel. The generator was positioned approximately 25 feet from the blower. The entire system took three people approximately 16 hours to install (Figure 21).

Figure 21. Activated Carbon Scrubber Installed at the House

Three activated carbon samples were placed downstream of the slide gate valve. Each of the three activated carbon samples was contained in a nylon mesh sock that allowed the MB, and all other potential contaminants, to adsorb on the carbon. One of these carbon samples was subsequently analyzed for disposal acceptance criteria as described at the end of this Section 3.7.5. The activated carbon used in the samples as well as in the scrubbers was 4x10 coconut shell activated carbon (TIGG 5CC 0408).

2.10.1 Air Flow Rate at Inlet to First Carbon Vessel

Measurements of air velocity within the duct leading from the house to the first carbon vessel were taken on 12/8/13 (prior to the fumigation), and after the fumigation on 12/12/13 at around 1200 hours (near the end of the carbon scrubber operation). Both sets of measurements were made with the carbon scrubber blower on and with the blower's damper set about half way open. An opening in the tent near the back porch allowed for intake of make-up air when the blower was on, (Figure 10). Air velocity measurements were made using a pitot tube connected to an electronic micro-manometer (Shortridge Instruments, Inc. Scottsdale, AZ, AirData Multimeter

ADM 860). Pitot tube traverses across the duct in both the horizontal and vertical directions were conducted per U.S. EPA Method 1 (http://www.epa.gov/ttnemc01/promgate/m-01.pdf). The micro-manometer was calibrated by the manufacturer prior to the field test. As required by EPA Method 1, to minimize bias due to turbulent flow, gas velocity measurements must be made at a location at least 8-duct diameters downstream and two diameters upstream from any flow disturbance. Since the inlet duct was made of flexible wire and rubber, a 12-foot long rigid piece of duct (20-inch inside diameter galvanized metal) was placed between the outlet of the house and the inlet to the first carbon bed to facilitate undisturbed velocity measurements. However, the rigid duct had to be shortened to 8 feet due to air leakage at the connections with the flexible duct, resulting in a length of only 4.8-duct diameters. Thus the minimum duct-length criterion of the method was not met. The implications of this are discussed in the Results Section 3.7.5.

2.10.2 Scrubber Temperature and Relative Humidity

Temperature and RH of the gas stream were measured at three locations within the carbon scrubber: in the rigid duct at the inlet of the first carbon vessel, between the two carbon vessels (at the outlet of the blower), and at the stack (outlet of the second carbon vessel). Temperature and RH were measured and logged at the inlet to the first bed using a HOBO model U10 (Onset Computer Corporation, Bourne, MA 02532), which was placed directly inside the duct. For the other two sample locations, temperature and RH were measured and the data logged using new, factory-calibrated HOBO Model 023-002 RH and temperature data loggers (Onset Computer Corporation, Bourne, MA 02532). For these two locations, the sensor tip was inserted into small holes drilled into either the metal housing of the blower or the metal stack, and then fastened to the sheet metal.

2.10.3 Scrubber MB Concentration

MB levels were measured within the carbon scrubber at the same sample locations used for the temperature and RH measurements. A dual-channel VIG Industries (Anaheim, CA) Model 20/2 flame ionization detector (FID) was used to continuously and simultaneously monitor MB levels at two of the three sample locations. Hydrogen gas (Airgas, Inc., Fort Lauderdale, FL) was supplied to the instrument from a pressurized gas cylinder for the flame source. MB data were collected, logged, and stored using a data acquisition system (IOtech Corporation, Cleveland, OH).

The FID calibration was checked before and after the carbon bed operation portion of the aeration using both a direct span and a bias span (calibration gases traveled through the sample line prior to detection). Calibration gases were obtained from Custom Gas Solutions (Durham, NC), and included 4.96 ppm MB in air, a 996 ppm MB in air, and a 5.28% MB in nitrogen. The FID was zeroed using ultra high purity air (Airgas, Inc.). The channel 1 detector of the FID served as the high level MB monitor, and was calibrated using the 996 ppm and 5.28% MB gases, while channel 2 was the lower level detector and was calibrated using the 4.96 and 996 ppm gases.

Gas samples from the carbon scrubber were pulled via the FID sample pump through unheated ¼" Teflon® tubing at a flow rate of four liters/min. Sample line length from each location to the

instrument was estimated to be less than 100 ft, yielding a response time of less than eight seconds.

2.10.4 MB Mass Balance Calculations for Activated Carbon Scrubber

The total mass of MB that exited the house and entered the carbon scrubber was calculated via integration of the area under the concentration versus time curve (see Results Section 3.7.4). That is, the mass flow of MB for each time increment was calculated and then summed for the entire time period in which MB was detected. The MB mass for each time increment (0.5 min) was calculated via the ideal gas law, using the gas volumetric flow rate, the MB gas concentration, and the temperature of the gas at the inlet to the first carbon vessel. A similar integration approach was used to calculate the total mass flow of MB between the carbon vessels and the amount of MB emitted to the atmosphere via the stack.

2.11 Ambient Air Monitoring

The study team monitored ambient conditions using both wireless air monitoring units and weather stations. Prior to the start of fumigation, personnel from EPA's Environmental Response Team (ERT) and Scientific, Engineering, Response and Analytical Services (SERAS) contractor deployed six ambient air monitoring units (Figure 22) strategically around the house (Figure 23). The units were deployed around the house and skewed downwind based on local meteorological data. Each unit contained a RAE Systems AreaRAE (RAE Systems, San Jose, CA) and a Honeywell Analytics (Morristown, NJ) MDA single point monitor (SPM). The AreaRAE, utilized a 10.6 eV lamp and a wireless radio frequency modem. Each unit was a five-sensor gas detector with a photo-ionization detector (PID) installed. The PID was calibrated to be responsive to MB using a 1.7 conversion factor[2] (RAE Systems, 2005: http://www.raesystems.com/products/multirae-family). The Honeywell Analytics MDA SPM employed a hydrogen bromide (HBr) Chemcassettes and ChemKeys (a MB Chemcassette was not available). The Chemkey stores HBr setup information and other functional information (i.e., flow rate, alarm levels, and compound concentration times) needed for accurate detection of target gases. The HBr Chemcassette is a medium onto which a known quantity of ambient air is concentrated. The unit has an internal sample pump which draws air at a manufacturers predetermined constant flow rate through a chemically treated paper tape. The tape darkens on exposure to the desired compound. At the end of each sample period the concentration is converted into an analog output signal. This output is then digitally stored on an attached data logger.

[2] See RAE Systems TN-106 for the proper way to implement a conversion factor. For high concentration initial doses, it may be desirable to use a dilution fitting. See RAE Systems Technical Note TN-167.

Figure 22. Air Monitoring Unit Containing an SPM (left) and an AreaRAE (right).

Figure 23. Ambient Air Monitoring Locations.

After deployment, the air monitoring units were calibrated at the study site. SERAS calibrated the AreaRAE units using zero air and volatile organic chemical (VOC) standards, (isobutylene 100 ppm). Once the AreaRAE units were calibrated to the VOC standard, a bump test was conducted with MB gas (5 ppm) to ensure that the units were reading MB in the 3-5 ppm range. If any drift occurred, the units were re-calibrated a second time to insure accuracy.

The SPMs were put through an internal calibration. Once the units were calibrated, they were bump tested against 5 ppm MB gas. Unfortunately, each of the SPM units failed to read MB and were removed from the air monitoring scheme.

Weathering stations used to monitor ambient conditions included the Florida Automated Weather Network (FAWN) and a mobile weather station (Figure 24). FAWN is a group of permanent weather stations positioned around the State of Florida. A permanent station is located on the Fort Lauderdale campus just north east of the house. A 600 Series mobile weather station (Weatherhawk, Logan, UT) was brought by EPA, and positioned just southeast of the house (Figure 25). Data from both units were read via wireless transmission.

Figure 24. FAWN Permanent Weather Station on the University of Florida

Figure 25. Portable Weatherhawk Weather Station Deployed on Site

2.12 Leak Detection

In addition to the RAE Systems AreaRAE monitors being used at the six stationary positions, two MultiRAEs (RAE Systems, San Jose, CA) were used as hand-held detectors for leak testing near the tarps surrounding the house. A team of two or more walked the perimeter of the cordoned off area around the house with a MultiRAE, and noted any non-zero readings. When the perimeter was below the action level, then the team entered the cordoned off zone (30 feet around the perimeter of the house) and approached the house, while noting any non-zero readings. When readings were above the action level (0.5 ppm) at the breathing zone of any

team member, the team exited the area, donned SCBAs and completed the leak survey with appropriate PPE. Readings were taken all the way around the house, including immediately adjacent to the tarp at multiple locations. Elevated readings were reported to the tenting and fumigation contractor for potential leak mitigation.

2.13 MB Fumigation Process

The MB (100%, Meth-O-Gas 100®, Great Lakes Chemical Co., West Lafayette, IN) was contained as a liquid in commercial 100-lb. metal cylinders (Figure 26). MB without chloropicrin was used to avoid the potential corrosive damage caused by chloropicrin. Since MB has a boiling point of 3.6°C, heat was added during introduction to insure that only gaseous MB was released from the end of the shooting hose. This was done by affixing the cylinder valve, by hose, to a 5-gallon-capacity heat exchanger (Figure 27). The heat exchanger contained a coiled metal tube through which the MB passed. The coil was surrounded by a water/radiator coolant mixture (60:40) which was heated by a propane burner to 90°C. The gaseous MB exited the heat exchanger through the shooting hose at about 70°C and then traveled as a gas through the shooting hose and exited into the shooting bucket inside the house. The certified applicator (Hammerhead Termite Control, Big Pine Key, FL) placed the MB cylinder on a balance and donned a full-face shield before he opened the MB cylinder (Figure 26). All MB released was measured gravimetrically.

Figure 26. MB Cylinder Being Opened

Figure 27. Heat Exchanger Used to Convert Liquid MB to Gaseous MB Exiting the Blue Shooting Hose

The working concentrations of MB during the fumigation were monitored at seven locations with two Fumiscope® thermal conductivity detectors (Figure 28) (Key Chemical Co., Clearwater, FL, accuracy approximately ±1 gram per cubic meter MB). One monitor was calibrated with MB in November, 2013 by Key Chemical Co., and the other Fumiscope was calibrated for Sulfuryl Fluoride and a correction factor was added to obtain MB equivalence. Fumiscope monitoring locations included the large classroom (southwest corner), the large classroom podium, the women's restroom (south), the attic and the room leading to the attic, the HVAC room (north), and inside the HVAC return duct. The Fumiscopes were fitted with air pumps that pull the interior MB-laden air through a monitoring line into the instrument which then gave a near real-time reading of MB concentration. During fumigation and aeration, the MB concentration was monitored 24hrs/day by authorized personnel (licensed and monitored by the state).

Figure 28. Fumiscope® Used to Monitor Working MB Concentrations

3 Results and Discussion

3.1 Results from Release and Monitoring of the MB

The time and amount of MB released into the house is provided in Table 5. Initially, 700 lbs of MB was introduced into the house over nine hours. The introduction of MB was delayed by two heat exchanger malfunctions (a pressure gauge fitting blew open in the first unit and inlet/outlet ports were reversed in the second unit) during the introduction of MB from the second 100 pound cylinder. The heat exchanger was repaired and the introduction continued. The target concentration (212 mg/l) was reached/exceeded at 2100 hours on December 9, 2013, starting the fumigation clock (time zero on Table 5), and was maintained for 48 hours. Two additional 50-lb increments of MB were added at 21 and 35 hours after the fumigation start time to maintain the MB concentration. The concentration of MB in each of the seven locations were comparable, which indicated adequate mixing within the house. Figures 29 and 30 are examples from two of those monitoring locations. Additional figures are in Appendix B.

Table 5. MB Release (lbs) and Concentration in House.

Time of MB Released				
Date	**Time (hr)**	**Elapsed Time (hr)**	**Inside Conc. (mg/l)**	**Lbs**
12/9/2013	1200	-9.0	0	Initiate
12/9/2013	1224	-8.6	34	100
12/9/2013	1627	-4.5	102	201
12/9/2013	1712	-3.8	136	100
12/9/2013	1811	-2.8	170	100
12/9/2013	1943	-1.3	204	100
12/9/2013	2100	0.0	212	Start
12/9/2013	2122	0.7	238	100
12/10/2013	1800	21	225	50
12/11/2013	0800	35	230	50

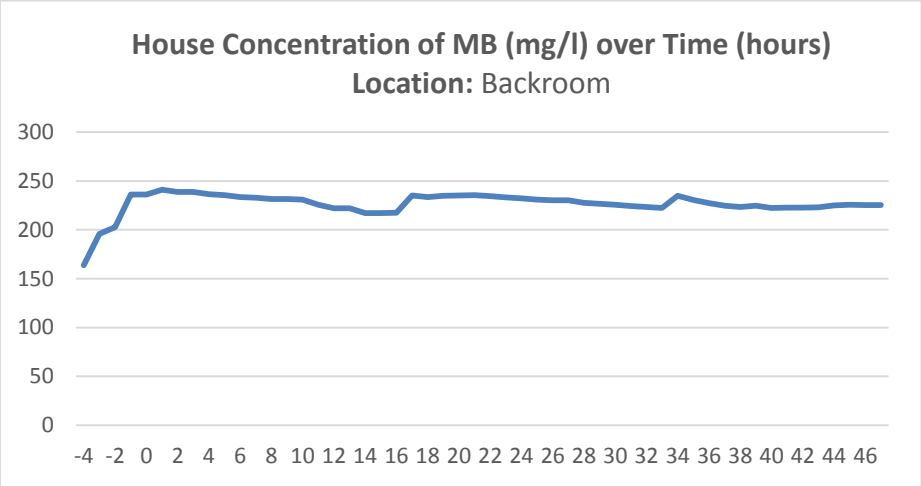


Figure 29. Concentration of MB (mg/l) over Fumigation Time (hr), Backroom Location

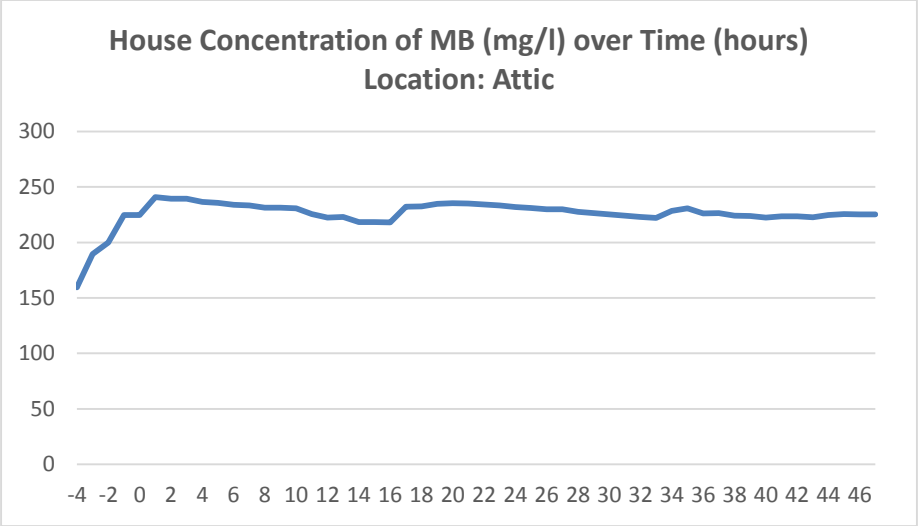


Figure 30. Concentration of MB (mg/l) over Fumigation Time (hr), Attic Location

There was a reduction in the MB concentration in the house over time. When fumigant was not being added to the house, the loss of MB can be observed (negative slope of the concentration line shown in Figures 29 and 30). We can assume that the loss of MB from the house was the sum of four contributions: leakage around the tarp material through penetrations (e.g., ducting connections from the house to the scrubbers), permeation through the tarp material, sorption into materials, and transformation or chemical reaction. However, MB is relatively stable so the transformation or chemical reaction contribution can be assumed to be close to zero. Additionally, according to a study conducted by Corsi et al. (2007), sorption and chemisorption with MB are negligible. The mattresses and other foams and fabric materials did not seem to increase the demand for the fumigant, nor did they seem to lengthen aeration time for this study. Sorption from these materials most likely reached equilibrium over a short time, bringing the sorption contribution to zero as the fumigation time increased. Note: these materials were only a small fraction of the overall volume of the space fumigated in this study. Specific studies to determine these affects should be conducted.

Assuming the loss of MB follows a first-order decay rate, the MB loss can be calculated from this concentration data. From this analysis, an estimated 91 kg (200 lb) of MB was lost during the entire fumigation, with leakage and permeation being the most likely contributors. Some leakage around the perimeter of the house was indicated by monitoring and observed, after the study, by the killing of the grass under the apron, see Figure 42 in Section 4.6. Sand was placed around the base of the house in effort to reduce the leakage. As noted in Table 6, the rate of MB loss decreased as the fumigation progressed in time. The decrease was most likely due to the implementation of these early leakage mitigation measures. Furthermore, toward the end of the fumigation (after the leakage mitigation was completed), 35 to 48 hours into the fumigation, there was little to no change in the leakage rate. At this point, the rate of about 1 mg/l/hr was observed.

To normalize based on the area of tent, the area that gas could potentially leak from, this leakage rate was divided by the total area of the tent (approximately 7200 ft^2) and multiplied by the volume inside the tent 1,284 m^3 (45,348 ft^3), resulting in a leak rate of 178 mg/hr per square foot of tented area. If conditions and materials are similar, this leakage value may be used at other sites to estimate fumigant loss/leakage. However, every site will have its own unique containment issues that will affect fumigant loss. In this case, the house is well understood and may represent a best-case seal as compared to typical structural fumigations.

In addition to the MB losses that can be calculated from analyzing the fumiscope data, there are also losses caused by added pressure when MB was introduced into the house. Over the course of the fumigation a total of 363 kg (800 lbs) MB, about 94 m^3 (3336 ft^3) of gas (28°C and one atmosphere of pressure), equaling about 7.4% of the entire volume of the enclosure, was released into the house. A 7.4% increase in volume produces a positive pressure inside the house. As an estimate of the loss of MB due to this positive pressure it is assumed that 7.4% of the total 363 kg or 27 kg (59 lbs) of MB leaked from the house, close in time to when the MB was added to the house. The mass balance of MB for the whole fumigation process will be discussed following the mass balance of MB in the scrubber system, Section 3.7.5.

Table 6. Loss of MB from the House in Milligrams per Liter per Hour

Time Range			Loss in mg/l/hr				
From (hr)	To (hr)	Δt (hr)	Podium	Ducting	Attic	Backroom	Average
0	21	21	1.46	1.66	1.65	1.67	1.66
21	35	14	1.15	1.12	1.11	1.11	1.11
35	48	13	1.15	1.02	0.79	1.13	0.98

3.2 House Temperature and Humidity Results

The heaters and steam vaporizers were turned on and off as described in Table 7. The average temperature and RH for each BI location inside the house is shown in Table 8. The average temperature inside the house during fumigation was 27.8 °C and the RH was 82.9%, these values slightly exceeded the desired fumigation conditions of 27 °C and 75% RH. One location only, the Mechanical Room did not meet or exceed the temperature set point of 27 °C.

Table 7. Heater and Humidifier on and off Cycles during Fumigation

Date: 2013 Dec. (day)	Time (hr)	Humidifier Bank 1*	Humidifier Bank 2*	Heater Bank 1*	Heater Bank 2*
7	1400	On**	On**	Off	Off
9	0710			On	On
9	1130	On	On		
9	1300		Off		
10	0130		On		
10	0335		Off		
10	0445	Off			
10	0620			Off	Off
10	1950		On		
10	2100		Off		

***A set of eight steam vaporizers was considered a "humidifier bank" and a set of two heaters was considered a "heater bank".**

****The steam vaporizers were refilled several times during the two days between 1400 hours 12/7/2013 and 1200 hours 12/9/2013, however, they were sometimes left empty, not generating, during this time.**

Table 8. Average Temperature (T) and RH during 2-Day Fumigation Inside House

Location ID	HOBO ID	Location	T (°C)	RH (%)
A	29	Entry room	27.2	81.7
B	17	Entry room	28.1	79.7
C	18	Office	26.6	84.3
D	10	Office	26.1	89.6
E	47	Kitchen	27.4	86.1
F	31	Kitchen	27.6	83.2
G	24	Mechanical room	28.4	80.0
H	34	Mechanical room	26	91.9
I	22	Hurricane Shelter	27.9	83.7
J	38	Attic	29.1	75.0
K	42	Attic	29.2	77.9
L	None	Storage room	N/A	N/A
M	57	Storage room	28.9	79.6
N	20	Classroom	29.3	77.2
O	44	Classroom	28.8	80.1
P	54	Back-porch	27.2	87.0
Q	11	Back-porch	27.6	83.8
R	55	Custodial	27.4	84.5
S	21	Restroom (Men)	27.9	82.8
T	30	Restroom (Womens)	27.6	84.3
U	43	Janitors Closet	28.2	79.6
V	58	Front porch	27.3	88.3
		Average	27.8	82.9

3.3 Leak Monitoring Around the Perimeter of the House Results

Leak detection evaluations were conducted using hand-held RAE Systems MultiRAE, with photo-Ionization detector with 10.6 eV lamp, around the cordoned-off area and directly next to the house, close to the tarps. The surveys were done by a variety of team members over the course of the fumigation, especially early in the process so that any leaks could be detected and addressed if possible. Leak information was given directly to the tenting and fumigation contractors, however, the readings obtained were not always recorded. The lack of notable findings, zero readings during monitoring at the caution perimeter may have resulted in a sense that the findings did not need to be recorded. Figure 31 shows the results of one leak-test survey taken when winds were unusually calm (less than one mile per hour winds reduced the dilution

affects and provided a worst case scenario leak detection). The readings recorded at the caution perimeter in Figure 31 (0.5-1.0 and 0.5 ppm) were the highest instantaneous readings; however, most readings were zero even at these locations. There were no sustained high (>0.5 ppm) readings recorded at any time at the caution perimeter. The concentration values near the house were obtained directly at the tarp fabric and do not reflect breathing zone concentrations. Breathing zone concentrations for the crew taking the readings were at least an order of magnitude lower than the concentrations obtained directly at the tarp using instrumentation extended away from body. Even when MB readings were high (an instantaneous high of 27 ppm in Figure 31) when touching the tarp there were no sustained high (>0.5 ppm) breathing zone readings for the monitoring crews.

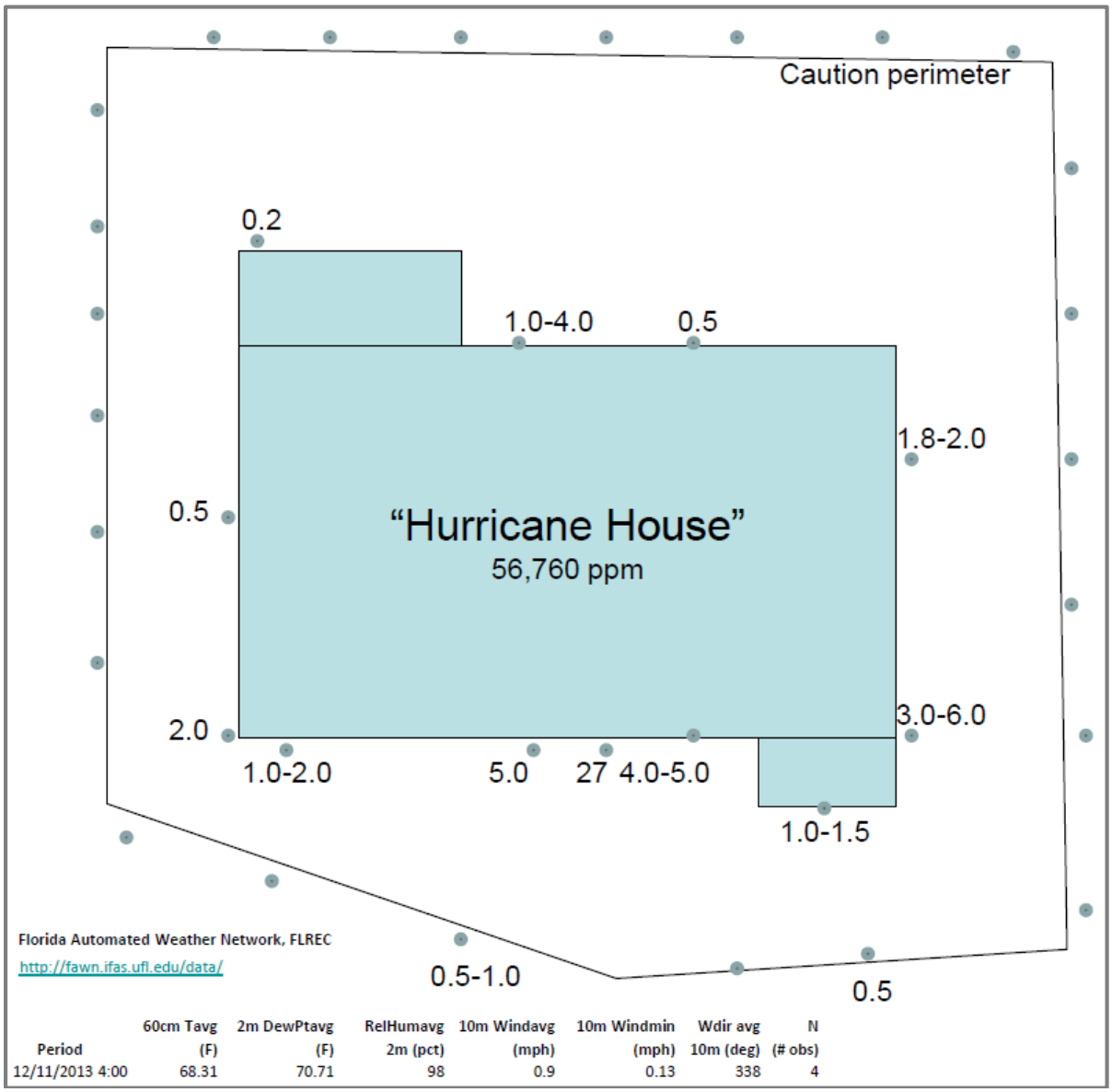


Figure 31. Leak Detection Results from December 11, 2013 at Approximately 4:30 a.m. Calm Wind Conditions. Dots without Numbers Indicate Zero MB Detected and Numbers Reflect Highest Instantaneous MB Concentrations (ppm).

3.4 Biological Indicator (BI) Results

3.4.1 Pre- and Post-Test BI Population Comparison

The spore population densities were recovered from the test coupons pre- and post-test and compared. No statistically significant differences were detected in the population densities of spores on pre- and post-test control samples (Table 9).

Table 9. Spore Population Densities on Pre- and Post-Test Control (Non-Exposed) BIs

BI Coupon Type	Pre-Test Population	Post-Test Population	n	p-value (two tailed Student's t-test)
Stainless Steel	2.2×10^6	2.5×10^6	10 pre-test, 10 post-test	0.1297
Glass	2.0×10^6	2.2×10^6	3 pre-test, 3 post-test	0.2499
Wood	9.6×10^5	4.6×10^5	3 pre-test, 3 post-test	0.0659

The abundance of viable spores on non-exposed BI coupons were similar before and after the field test, indicating that time in storage did not significantly affect the spore titer on the BIs. Recoveries from glass and stainless steel were within the targeted range (2.0 to 5.0 × 10^6): recoveries from wood, however, were lower than the amount inoculated onto these coupons. These results were expected, as recoveries from glass and steel are typically between 75 – 95% of the inoculum, while recoveries from wood have historically been between 1 – 25% of the inoculum. From Table 9, Spore Population Densities on Pre- and Post-Test Control BIs, it is apparent that glass and wood demonstrated recovery efficiencies of 91% and 44% of the stainless steel control carriers for pre-test evaluations, and 88% and 18% for post-test evaluations, each respectively. All carriers were inoculated with a population density (as determined by the BI supplier) of 4.2×10^6 CFU / carrier. Accordingly, mean recovery efficiencies from stainless steel, glass, and wood were 52%, 47%, and 23%, respectively. It is therefore presumed that the lower estimates of spore population density on wood coupons were due to lower recovery efficiencies from the porous wood surfaces and not due to inactivation of spores on the surface.

3.4.2 Spatial Assessment of Efficacy (Qualitative Test) Results

Results from all 22 locations are shown in Table 10.

Table 10. BI Results from the Spatial Assessment of MB Fumigation Efficacy

Location	Location ID	Test BIs (growth-positive BIs / total BIs)		Procedural Blanks (growth-positive BIs / total BIs)	
		Wood	Glass	Wood	Glass
1	A	0/4	0/4	0/1	0/1
2	B	0/3	0/4	0/1	0/1
3	C	0/4	0/4	0/1	0/1
4	D	0/4	0/4	0/1	0/1
5	E	0/4	0/4	0/1	0/1
6	F	0/4	0/4	0/1	0/1
7	G	0/4	0/4	0/1	0/1
8	H	0/4	0/4	0/1	0/1
9	I	0/4	0/4	0/1	0/1
10	J	0/4	0/4	0/1	0/1
11	K	0/4	0/4	0/1	0/1
12	L	0/4	0/4	0/1	0/1
13	M	0/4	0/4	0/1	0/1
14	N	0/4	0/4	0/1	0/1
15	O	0/4	0/4	0/1	0/1
16	P	0/4	0/4	0/1	0/1
17	Q	0/4	0/4	0/1	0/1
18	R	0/4	0/3	0/1	0/1
19	S	0/4	0/4	0/1	0/1
20	T	0/4	0/4	0/1	0/1
21	U	0/4	0/4	0/1	0/1
22	V	0/4	0/4	0/1	0/1
Total		0/87	0/87	0/22	0/22
		Positive Controls (growth-positive BIs / total BIs)		Negative Controls† (growth-positive BIs / total BIs)	
		Wood	Glass	Wood	Glass
Not Exposed		24/24	24/24	2/24	0/24

†Note: Negative Control BIs were not sterilized prior to packaging and were not guaranteed sterile as received from Yakibou Inc., therefore growth-positive negative controls were not unexpected. Results from lab-sterilized (autoclaved) BIs (Table 11) indicate whether BI culture procedures were performed aseptically.

None of the 87 wood or 87 glass test BIs had viable spores following fumigation. One wood test BI (Location 2) and one glass test BI (Location 18) were not analyzed. At Location two only three wood test BIs, instead of four, were deployed. At Location 18 the glass coupon was missing from inside the Tyvek® envelope (apparently it was not placed into the envelope during laboratory preparation). Similarly, the 22 wood or 22 glass procedural blanks (not inoculated, fumigated) showed no turbid media (no growth) following attempted culture. These results verify that the MB fumigation was effective throughout the entire house, as no spatial differences in BI inactivation were apparent. No growth on any of the procedural blank BIs suggests that inadvertent contamination during field or lab procedures was not apparent. All 24 wood and 24 glass positive-control coupons (inoculated, not exposed) were indeed positive for growth upon

analysis. Two of the 24 negative control (not inoculated, not exposed) wood coupon BIs were positive upon analysis, none of the 24 negative control glass BIs were positive. The two growth positive negative control wood BIs were not surprising, as the BI producer did not guarantee sterility of these coupons as provided. None of the microbiology lab negative controls were positive for growth, suggesting that inadvertent contamination of samples during lab procedures was not apparent (Table 11).

Table 11. Results from the Analysis of Microbiology Laboratory Control Samples

Microbiology Lab Controls	Results (number growth-positive / total analyzed)
10ml TSA in 25mm Tubes	0/3
TSA Plates	0/3
10ml TSA in 18mm Tubes	0/3
Inoculum-spreading beads	0/1
0.9ml PBST Dilution tube	0/1
Cell spreaders	0/6
Lab-Sterilized Negative Control BIs	0/3 steel, 0/3 glass, 0/3 wood

3.4.3 Temporal Assessment of Efficacy - Quantitative Test (Time-Series Test) Results

Results from the quantitative tests of spore survival during the temporal assessments of efficacy are shown in Table 12.

Table 12. BI Results from the Temporal Assessment of MB Fumigation Efficacy

Time Point (hours)	Sample ID	Test Coupons Total CFU Recovered		Procedural Blanks Total CFU Recovered	
		Wood (n=6)	Glass (n=6)	Wood (n=2)	Glass (n=2)
16	W	0 Ψ	828 ± 2027†	0	0*
24	X	0	0	0	0
32	Y	0	0	0	0
40	Z	0	0	0	0

†Viable spores recovered from 1 of 6 replicate BIs. 4967 CFU recovered from replicate #6 of 6.
ΨFor replicate #2 of 6), one filter-plate sample (1ml analyzed) yielded 1 CFU. When 7.5ml from the same sample was analyzed, zero CFU were observed. No CFU were observed from the other 5 replicate wood BIs at the 16 hour time point.
***Contamination by non-target bacteria was observed on both glass procedural blanks at 16h time point. For replicate 1, 2 CFU and 14 CFU were observed on the 1 ml and 7.9 ml filter-plates samples, respectively. For replicate 2, 4 CFU and 50 CFU were observed on the 1 ml and 7.8 ml filter-plate samples, respectively**.

Analysis of the time-series coupons showed viable spores (4967 CFU) were recovered from only one of the six replicate glass coupons exposed for 16 hours, resulting in an average recovery of 828 spores across the six replicates. The remaining 5 of 6 replicates showed zero recovered viable spores. Similarly, only one wood coupon exposed for 16 hours had any viable spores. This wood

coupon had only one CFU detected during the 1 ml filter-plate analysis. Interestingly, filter-plate analysis of the remaining 7.5 ml resulted in no growth. Log reductions for all wood BIs during the quantitative temporal assessment portion were greater than or equal to 5.7. All glass, other than the 16-hour exposure, were greater than or equal to 6.3 LR. The 16-hour exposure for glass yielded a 3.41 LR.

Contamination by non-target bacteria was detected on both glass procedural blank coupons at the 16 hour exposure point. Contamination on procedural blanks is not unexpected, as discussed before. Overall, the MB treatment was efficacious, as 46 of 48 test coupons were completely negative for growth of *Ba* Sterne at any of the time points tested. Exposures at the 16 hour time point, where 10 of 12 coupons were completely inactivated, just missed the 6-log reduction efficacy criteria. These temporal results indicate that the fumigation was efficacious (> 6 LR) early (after 24 hours) in the process, at the temporal extraction location in the house.

3.5 Surface Sample (Sponge Wipe Samples) Results

Results from the surface sample wipes are shown in Table 13. Two blank surface samples collected showed no growth upon microbiological analysis. Three of the four collected pre-fumigation surface wipe samples showed the abundance of background organisms (non-*Ba* Sterne). Similarly, three of the four post-fumigation surface wipe samples showed background contamination after fumigation (also non-*Ba* Sterne organisms). Coupon sample collection and other post-fumigation activities occurred before wipe sample collection. Both of those activities may have contaminated the surfaces that were later wipe sampled. The wipe samples that follow fumigation should be conducted in concert with all of the other post-fumigation activities in mind. Recontamination of the house, even with organisms that do not have negative health consequences, may interfere with post-fumigation sampling.

Table 13. Recovery Results from the Surface Samples Collected within the House

Sample	Sample ID	Location	Pre- or Post-Fumigation	Recovery (CFU)
Swab1	HHMB 07051	Kitchen wall near oven	Pre	0
Swab2	HHMB 07050	Server room desk	Pre	TNTC (non-*Ba*)
Swab3	HHMB 07036	Floor by back door (west)	Pre	TNTC (non-*Ba*)
Swab4	HHMB 07118	Reception desk	Pre	TNTC (non-*Ba*)
Swab5	HHMB 07049 (blank)	Blank	Pre	0
Swab6	BW001	Reception desk	Post	TNTC (non-*Ba*)
Swab7	FW002	Kitchen cabinet	Post	TNTC (non-*Ba*)
Swab8	LW003	Server room desk	Post	0
Swab9	W004	Floor by back door (west)	Post	TNTC (non-*Ba*)
Swab10	Blank	Blank	Post	0

TNTC = Too Numerous to Count (background organisms and/or contamination of sample)
Non-*Ba* = Organisms found on the wipe samples were not classified as *Ba*

3.6 Ambient Air Monitoring Results

Ambient outdoor conditions were monitored throughout the fumigation process. Perimeter monitoring was continuously conducted during fumigation using the wireless AreaRAEs. During this process, SERAS calibrated each unit daily against the VOC standard, and bump tested with 5 ppm of MB. Whenever any drift occurred, due to outside factors, the units were re-calibrated. AreaRAE readings were logged throughout the fumigation process (See Appendix B). The study team utilized the readings to determine compliance with the 0.5 ppm MB action levels developed for this site during fumigation operations. Any readings that were above the action levels were further investigated using a MultiRAE handheld unit.

On occasion elevated readings seen on the AreaRAEs were investigated with a handheld unit. The elevated readings were shown to be false positives for several different reasons. A phenomenon known as "Hotbox syndrome" (which is caused by the sun heating the black Pelican™ case housing the AreaRAEs) caused the units to exceed their operable temperatures. The units were then cooled or replaced to improve accuracy.

Vehicle emissions contributed to at least one known false positive reading during fumigation (and later during aeration). A truck parked close to Location 101 on December 10, 2013. The AreaRAE

unit exceeded the action level of 0.5 ppm and was investigated. Upon examination with a handheld, the elevated readings were shown to be caused by the idling truck.

Other contributing factors that led to investigations were moisture from high humidity. High humidity was encountered during each day of fumigation phase, often from around 9 PM until just after dawn. Data from area weather stations indicated that RH rose above 80% several times for extended periods. The high moisture content in the air can create interference for the AreaRAE's PID sensor. Virtually all units indicated elevated VOC levels (Appendix B) at one time or another. Investigations with a handheld MultiRAE unit determined that sustained elevated readings were false positives possibly due to moisture. SERAS recalibrated the AreaRAE units during times of high humidity to help clean the sensor and improve their accuracy. There were no substantiated, sustained elevated levels (> 0.5 ppm) of MB at any of the AreaRAE monitoring sites at any time during the fumigation.

At approximately 1700 hrs, 12/11/2013, the air monitoring units were re-deployed/re-named to prepare for aeration and to better surround the scrubber units (Figure 32). Location 101 was removed from the MB release point and repositioned as Location 201 near the command post. Location 102 was renamed Location 202. Location 103 was removed from near the storage buildings and redeployed as Location 205 north of the scrubbers (between the greenhouses and the house). Location 104 relabeled as Location 203. Location 105 was stayed in the same location but was given the name Location 204. Lastly, Location 106 moved closer to the personnel air monitoring the scrubber process, and renamed Location 206.

Throughout the aeration process, the AreaRAE readings were datalogged (See Appendix B). As noted earlier, vehicle emissions were recorded on AreaRAEs at Location 201 and 202 as vehicles parked at the command post or traversed the nearby roadway. The remainder of the AreaRAE units did not detect any significant readings.

Outdoor wind speed, temperature and humidity are also plotted by day in Appendix B. Wind speed can have a significant effect on ambient MB concentrations. This effect is further addressed in the Section 3.8, Modeling.

Figure 32. Re-Deployed Locations of Air Monitoring Units during the Aeration Process

3.7 Activated Carbon Scrubber Results

3.7.1 Flow Rate at Inlet to First Carbon Bed

The average velocity, in the duct preceding the first carbon vessel, measured prior to commencement of the fumigation was determined to be 1185 ft/min, corresponding to a flow rate of 2583 ft^3/min. The post fumigation velocity and flow rate measurements were taken toward the end of the carbon bed operation phase (at time 0000 hrs on 12/12/13), and were determined to be 1280 ft/min and 2790 ft^3/min, respectively. While these pre- and post-fumigation flow results are correlated fairly well with each other (within 8%), the minor

difference is likely due to having a larger diameter opening in the tarp near the large porch at the back of the house (during the latter measurement) that allowed less resistance for make-up air to enter the house while operating the carbon bed system blower. Refer back to Section 2.2 and Figure 10 of this report for further details and discussion of the custom made tarp opening created for aeration.

3.7.2 Temperature and RH at the Carbon Scrubber during Scrubbing

The results for the temperature and RH measurements of the gas at the inlet to the first carbon bed are shown in Figure 33. Both temperature and RH immediately elevated once the aeration began (at approximately 2100 hours on 12/11/13). Temperature climbed from an ambient level of approximately 21 to 27 °C, consistent with the house fumigation target temperature of 27 °C. During the aeration process, the temperature at the inlet gradually decreased a few degrees until the blower was shut off.

Once aeration began, the RH at the inlet spiked from a level of 88% (a level consistent with ambient RH) to over 98%. This initial spike in RH may have been due to excess moisture originating from the fumigation inside the house that had condensed within the duct near the gate valve. Following this initial spike, the RH fell to 80% during the next 15 minutes, a level consistent with the fumigation target RH. At this point, the RH level continued to decrease, but at a lower rate, until it reached a minimum of 75% at 2224 hrs (1-hr, 24-min scrubber time). Then the RH slowly began to increase again, in conjunction with a decrease in temperature. This is consistent with having no change in absolute humidity of a gas, resulting in an RH increase with a decrease in temperature.

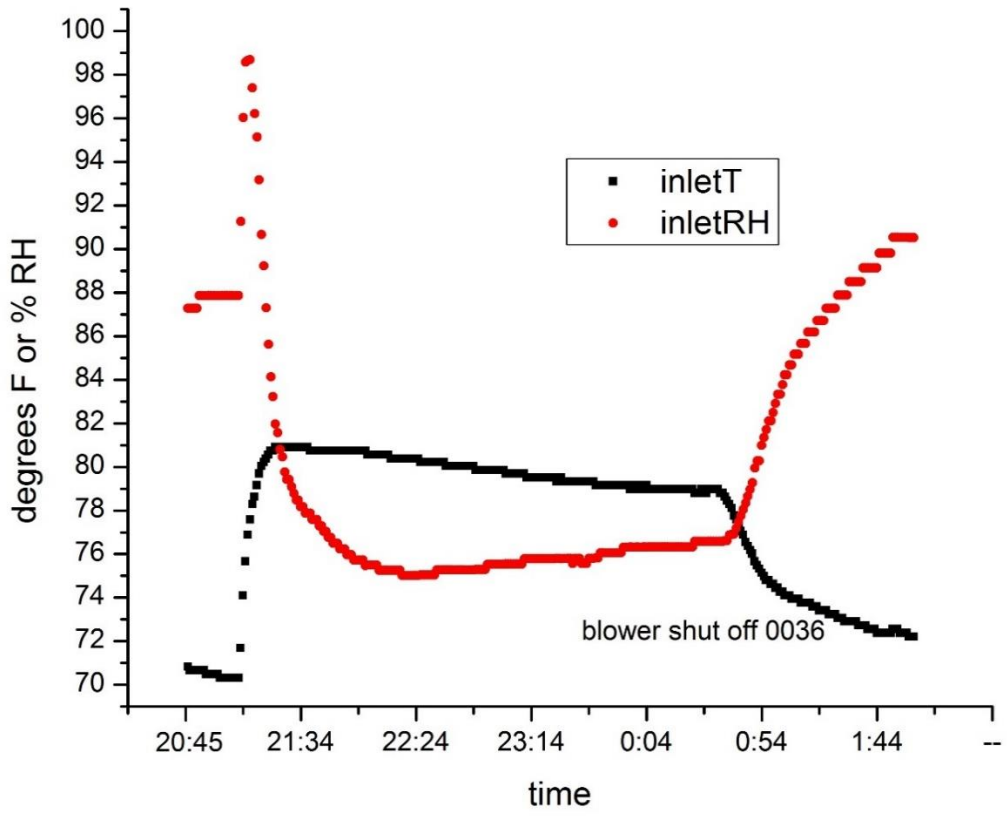


Figure 33. Temperature and RH Levels at the Inlet to the First Carbon Bed

3.7.3 Temperature and RH between the Carbon Beds and in the Scrubber Stack

The results for the temperature and RH measurements of the gas between the carbon beds (i.e., at the blower) and in the stack are shown in Figure 34. The temperature of the gas at the blower location (outlet of first bed) was initially consistent with ambient temperature, but rose rapidly once aeration began, and reached its maximum of 44°C at 2120 hrs (20-min scrubber time) This spike in gas temperature is presumably due to the heat of adsorption that was occurring on the first carbon bed. After the initial spike in temperature, the blower gas temperature gradually declined throughout the time the blower was operating, with the exception of a bump in temperature (from 35°C to 38°C) beginning at 2200 hrs (1-hr scrubber time). When the blower was shut off at 0036 hrs (3-hr, 36-min scrubber time) the following day, the temperature of the gas within the duct near the blower had decreased to 31°C.

During the initial portion of the carbon bed operation, the stack gas temperature generally mimicked the blower temperature, but with a time lag of 5-10 minutes. The time lag in temperature for the two locations in the carbon bed system may be attributable to the time needed to heat the carbon in the second bed, and not due to the gas residence time of each carbon bed, calculated to be ~ 11 s. At 2130 hrs (30-min scrubber time), the temperature of the stack gas peaked at 42°C, and then gradually declined to about 35°C at 2230 hrs (1-hr, 30-min scrubber time), where it remained stable at that temperature for over an hour. The temperature then increased to 41°C, at which time the blower was turned off. This second rise in stack

temperature was likely due to MB breakthrough from the first carbon bed carrying over to the second bed, with the accompanying heat of adsorption in the second bed.

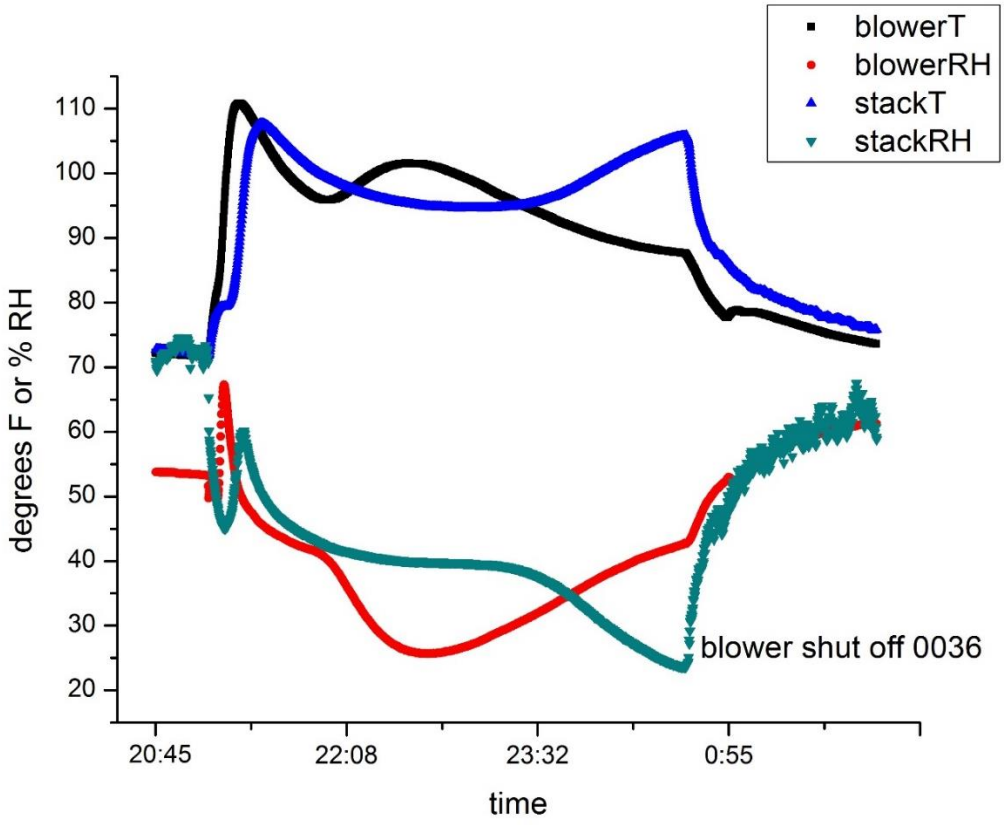


Figure 34. Temperature and RH Levels at the Blower and in the Stack, during Scrubbing

The blower RH level was initially at a level of ~ 54%, then spiked to nearly 70% when aeration began. This initial spike in RH may have been due to a number of factors, such as the driving off of moisture that had condensed and accumulated in the duct, similar to what may have happened at the carbon bed inlet. Following this short term initial increase in RH, at the blower, it trended downward to a minimum of 25%, by 2230 hrs (1-hr, 30-min scrubber time). The RH at the blower then increased, until it reached a level of about 45% at the time the blower was shut off. This fall in the blower location RH, followed by its subsequent increase, may be due to the first carbon bed's adsorption of water vapor to the point of reaching its capacity. That is, we suspect that once all active adsorption sites on the first carbon bed were utilized for capture of water vapor and MB, no additional water vapor could be adsorbed onto the carbon. Additionally, preferential adsorption for MB rather than water vapor may also have contributed to the release of water vapor from the first carbon bed back into the gas stream. There is also the possibility that the RH at the blower may have been influenced by gas temperature at the blower, more so during the latter half of the carbon bed operation, when the temperature was decreasing.

The average stack RH level just prior to the start of aeration was 72%. Once aeration began, the stack RH plummeted to a level consistent with the initial RH levels seen at the blower. From then

on, the downward trend in RH levels in the stack gas followed blower RH trends, with a similar time lag observed with the gas temperatures. However, unlike the blower RH, the stack RH level never appeared to reach a minimum level until the blower was stopped. This apparent continued removal of water vapor in the second carbon bed is presumably due to the availability of adsorption capacity (for both water vapor and MB) of the second bed. Once the blower was turned off, stack RH levels quickly trended upward, toward ambient levels.

3.7.4 MB Levels during Aeration

Initially, gas sample from the inlet to the first carbon bed was routed to channel 1 of the FID, gas sample from between the two carbon beds was measured using channel 2, and no gas sample was taken at the stack. As the carbon bed system scrubbing operation proceeded and MB breakthrough occurred for the first carbon bed, the study team switched the sample lines and channels, as needed, to ensure the appropriate data were obtained from all three sample locations. The result was that for the latter portion of the carbon bed scrubbing, more emphasis was placed on securing data for the stack location, resulting in intermittent time periods in which no MB data were available for a particular location. Towards the end of the carbon bed system operation, gas sampling occurred at the inlet to the carbon beds and at the stack. Monitoring of the carbon bed system was stopped (the blower was turned off at 0036 hrs (3-hr, 36-min scrubber time) on 12/12/13 when the stack MB concentration was nearly equivalent to the MB concentration in the house.

The MB levels observed in the duct at the inlet to the carbon bed during carbon bed operation are presented in Figure 35. Just prior to turning the blower on to start the aeration process (at 2100 hrs), the MB level in the duct was ~ 5,000 ppm. The presence of MB in the inlet duct prior to aeration indicated some leakage from the gate valve in the duct between the house and the first carbon bed, which was expected. Once the blower was turned on, the MB level peaked immediately to 41,000 ppm, and then thereafter gradually decreased over time. There were three periods of time when FID gas inlet sampling was temporarily suspended to allow for sampling at the stack: 1) at 2157 hrs (57-min scrubber time); 2) at 2246 hrs (1-hr, 46-min scrubber time); and 3) at 2327 hrs (2-hr, 27-min scrubber time). The carbon system blower was shut off when the MB concentration at the scrubber inlet decreased to 137 ppm, ending active aeration through the carbon scrubber.

The MB levels measured at the blower location (between the carbon beds) are shown in Figure 36. As with the sampling at the inlet and stack locations, there were intermittent periods when gas sampling for the blower location was stopped to allow for sampling of the other two locations; hence no data are available for those time periods. Breakthrough of MB from the first carbon bed occurred around 2145 hrs (45-min scrubber time). MB emission levels from the first carbon bed then continued to climb until sampling stopped for this location at 2339 hrs (2-hr, 39-min scrubber time), when MB levels had reached 2843 ppm. From approximately 2220 hrs until 2312 hrs, MB levels increased relatively rapidly at a rate of about 36 ppm MB per minute. However, during the last few minutes of sampling at this location, MB emissions levels began to

stabilize, with the rate of increase in MB levels diminishing to approximately 5 ppm MB per minute.

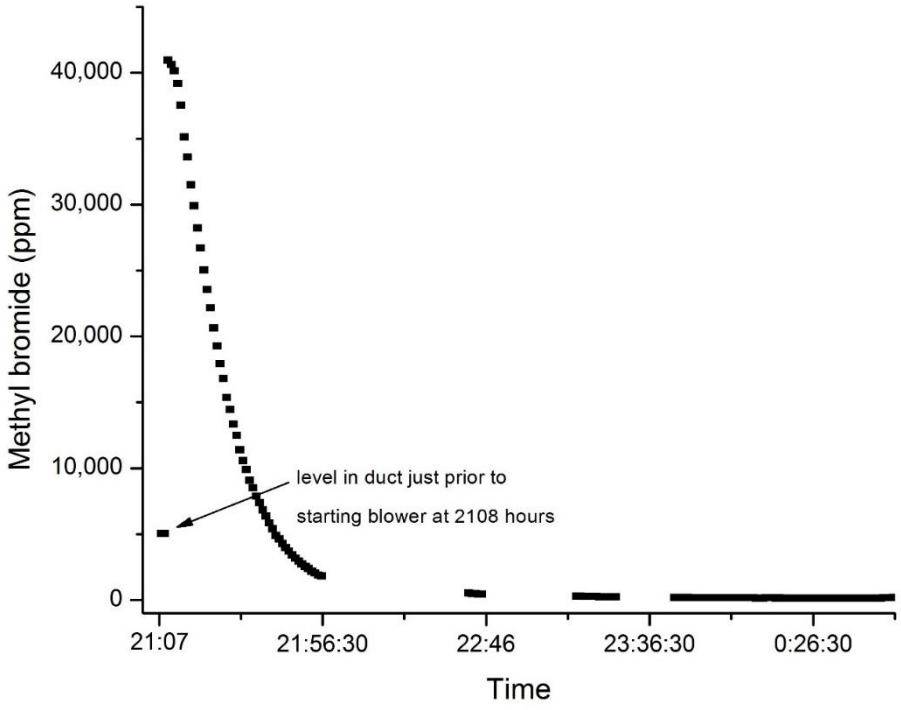


Figure 35. MB Concentration in the Duct at the Inlet to the First Carbon Bed during Scrubber Operation

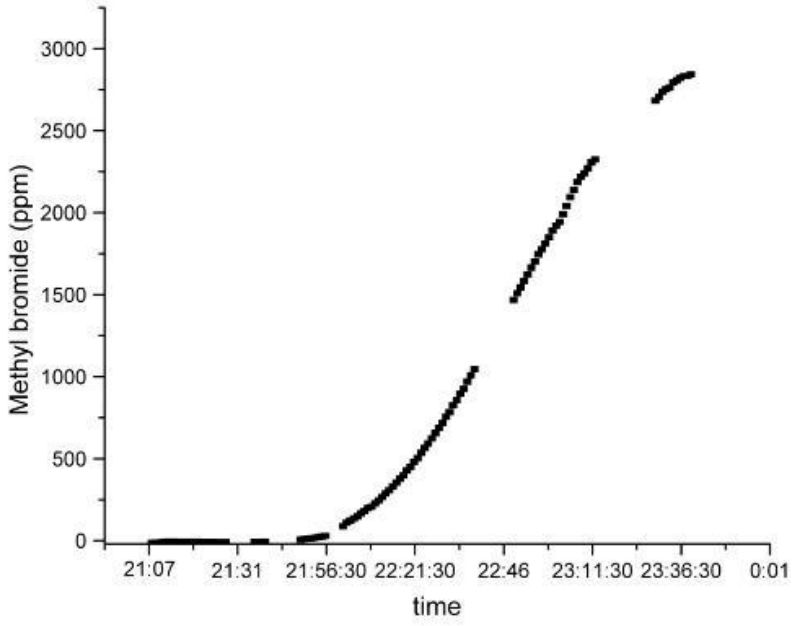


Figure 36. MB Concentration at the Blower (Between the Carbon Beds) during Scrubber Operation

The MB levels measured at the stack location during carbon bed system operation are shown in Figure 37. Stack sampling occurred intermittently from about 2133 hrs until 2248 hrs. During that time period, the MB levels were reading negative on the FID. (We note that the instrument was zeroed using ultra high purity air, but would read negative values when sampling ambient air.) Sustained positive readings on the FID (i.e., breakthrough of MB from the second bed) occurred at 2305 hrs (2-hr, 5-min scrubber time), with MB levels continuing to climb up to 156 ppm, when blower operation was terminated at 0036 hrs on 12/12/13 (3-hr, 36-min scrubber time).

Next, the study team shut down the scrubber system, removed the inlet duct from the carbon beds and sealed the beds. The duct was also removed from the valve gate, and a fan was placed at the valve gate opening to blow fresh air into the house aiding the natural aeration process. The following morning additional openings were made in the tarps to aid the natural aeration process. One of the MB sampling line (bathroom sample line) was switched from a Fumiscope to the FID (channel 2) detector. This was done to enable more accurate MB readings within the house, since Fumiscopes are not sensitive enough at low levels, i.e., < 1 mg/L (Fumiscope Version 5.1 Manual pg. 2; personal communication with Rudolf Scheffrahn, UF Professor of Entomology; email on 2/6/14). In addition, personnel wearing SCBAs entered the house at this time to obtain the *Ba* (Sterne) inoculated coupons. Sampling of the bathroom air represented a space in the house with limited air ventilation and most likely some of the highest remaining MB concentrations. Sampling of the bathroom with the FID instrument commenced around 1040 hrs, and continued until 1311 hrs on 12/12/13.

The results for MB sampling within the house (bathroom) during a portion of the natural aeration are shown in Figure 38. When FID sampling began at 1042 hrs, the MB level was 196 ppm, and had dropped to 16 ppm at 1310 hrs. From the curve on Figure 38, the concentration decay rate in this bathroom is estimated to be 0.38 mg/l/hour.

3.7.5 MB Mass Balance for Activated Carbon Bed System and for Entire Fumigation

Based on the MB levels measured at the inlet to the first carbon bed, as shown in Figure 35, the total mass of MB entering the carbon system was calculated to be 243 kg (536 lb). From integration of the MB levels in Figure 36, the total mass of MB estimated to have exited the first carbon bed was 96 kg (211 lb), and integration of the data in Figure 37 resulted in an estimated 1.8 kg (4 lb) exiting the stack while the carbon system was operating. By difference, it is estimated that 147 kg (325 lb) MB were collected on the first carbon bed, and 94 kg (207 lb) were captured on the second bed. With 2495 kg (5,500 lb) of carbon in each bed, the adsorption of MB onto Bed 1 is 2.9 kg (6.5 lb) MB per 45 kg (100 lb) carbon, and the second bed adsorption was 1.9 kg (4.1 lb) MB per 45 kg (100 lb) carbon. The overall removal efficiency of MB by the carbon bed system, therefore, is 99% for MB that enters the scrubber system. Please refer to Figure 39 for a diagram of the mass balance for the carbon system.

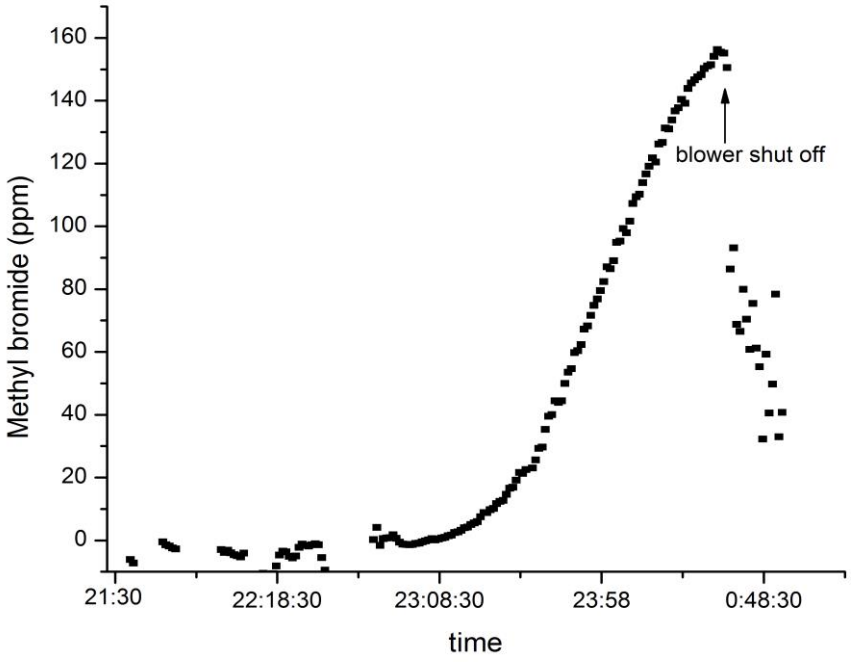


Figure 37. MB Concentration at the Stack during Scrubber Operation

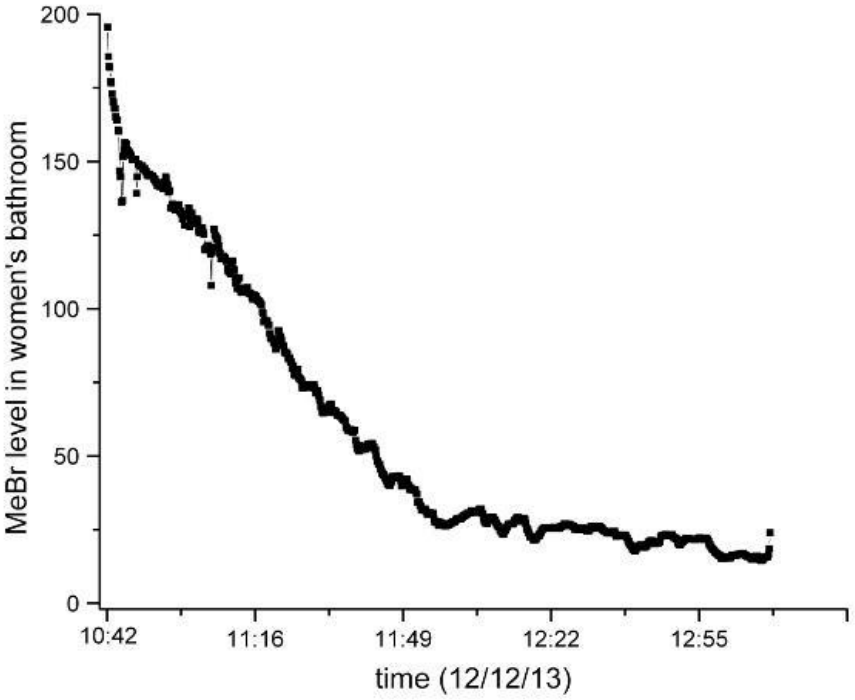


Figure 38. MB Concentration (PPM) within a Bathroom during Natural Aeration

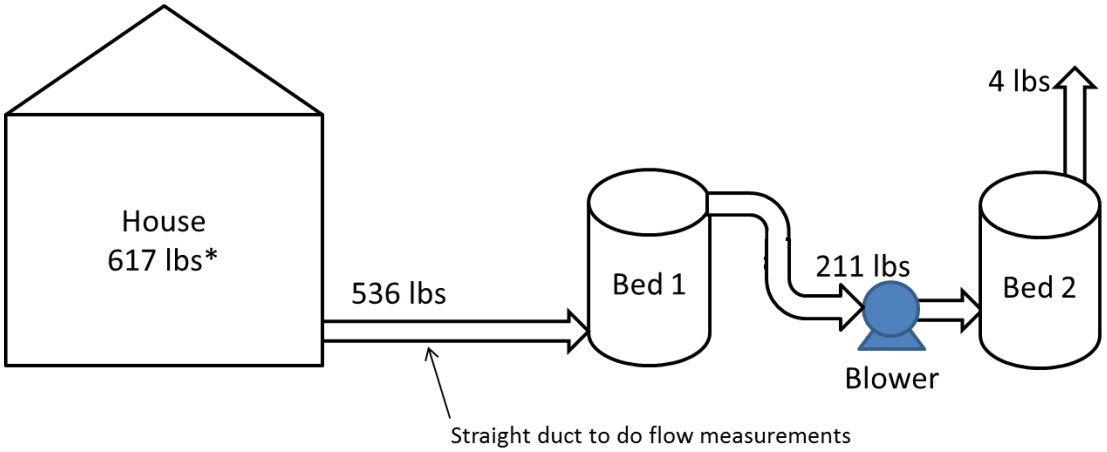
The MB concentration in the house measured by the Fumiscope was 218 mg/L (0.22 oz/ft^3), just prior to starting the carbon scrubber, which is equivalent to 56,400 ppm at 27 °C. Using a house volume of 1,284 m^3 (45,348 ft^3) (UF provided estimate of air volume, excluding solid objects, within the house), the total mass of MB in the house just prior to operation of the carbon scrubber system was calculated to be 280 kg (617 lbs). At the end of the carbon bed operation, the Fumiscope was reading 1 mg/L (0.001 oz/ft^3) which is equivalent to 1.3 kg (3 lbs) total MB left in the house, 279 kg (614 lbs) of MB was pulled from the house.

The initial reading taken by the FID after starting up the scrubber was 41,000 ppm, 27% lower than the Fumiscope reading of 56,400 ppm. The most likely reasons for the difference would include low FID reading caused by ambient dilution air entering the duct (e.g., where the duct was connected to the house) or ambient dilution air entering through tent leaks near where the duct was connected to the tent. All ambient air entering the house near, or at, the scrubber duct would contribute to dilution of the MB concentration as this air is mixed with the gas pulled from the house toward the first carbon bed where the FID sampling port was located. Make-up air entering the house near the back porch may also have mixed poorly with gases throughout the house (though mixing fans were left on during this period of time), traveling through channels directly to the exhaust duct and to the FID sampling point.

There are numerous possibilities for the discrepancy between what was removed from the house as calculated using the FID carbon scrubber measurements 243 kg (536 lb), 13% lower than the MB mass calculated using the house volume and Fumiscope readings 279 kg (612 lbs). Differences could be attributed to inaccuracy in MB measurements (for either the Fumiscope-measured levels in the house and/or the FID-measured levels in the exhaust gas), an inaccurate house volume estimate, or an inaccurate blower gas-flow-rate measurement.

As stated earlier, accurate gas velocity readings in the duct are critical for obtaining an accurate mass emission rate. We followed U.S. EPA stack gas flow measurement procedures, with the exception of not having a sufficient length of straight duct to minimize turbulent flow. Turbulent flow may have been present due to shorter straight-duct length where measurements were made, resulting in biased flow measurements. In addition, EPA Method 2 requires that static pressure be measured within the duct, and that the volumetric flow rate should be adjusted for this relative to atmospheric pressure. Static pressure was not measured within the duct, and so this adjustment could not be made.

The mass balance of MB for the entire fumigation includes the total mass of MB released in the house, 363 kg (800 lbs); the MB leakage rate calculated for the combination of penetration around the tarp material, permeation through the tarp material and sorption into other materials within the house, 91 kg (200 lbs), as estimated in Section 3.1; the MB forced from the house by displacement of fumigant as a result of the addition of 363 kg (800 lbs) of MB was 27 kg (59 lbs), as estimated in Section 3.1; the MB taken to the scrubber, 243 kg (536 lbs); and the MB left in the house at the end of scrubbing, estimated to be 1.3 kg (3 lbs). Remarkably, based on these estimates, the entire fumigation mass balance of MB (363-91-27-243-1=1 kg) results in only 1 kg (2.2 lbs) of MB unaccounted for.



*Calculated MB mass based on Fumiscope reading of 218 mg/L, house volume of 45,348 ft^3, air flow rate of 2790 ft^3/min, and FID readings in scrubber system ducts

Figure 39. Mass Balance of MB for the Activated Carbon Scrubber

Once the fumigation was completed the scrubber system was disassembled and staged for pickup by a commercial carrier. The activated carbon samples that were placed in the duct prior to the scrubber operation were removed and placed into sample containers. One of the samples was sent to a commercial lab for analysis for contaminants such as heavy metals that would affect the carbon regeneration process. The other two samples were extra or backup samples. Once the analysis was complete TIGG and the state of Pennsylvania reviewed the analytical results and determined that the carbon could be regenerated. This analysis and acceptance process took about six weeks and equipment was then picked up on January 30, 2014. The activated carbon vessels were delivered to Siemens (Darlington, PA) to regenerate the activated carbon. The activated carbon was removed from the vessels and placed into a rotary kiln reactivation furnace where the carbon was heated to 927 °C. Any adsorbed MB was volatized and the off-gas from the kiln passed through an afterburner to further destroy the organic portion and pyrolize any remaining volatile bromines. Then the flue gas was sent through a scrubber to remove any halogenated compounds.

3.8 Dispersion Modeling and Results

The Quick Urban & Industrial Complex (QUIC) Dispersion Modeling System is a fast response urban dispersion model that runs on a laptop. QUIC will account for the effects of buildings in an approximate way and provide more realism than non-building aware dispersion models. The QUIC model was used with inputs of MB leakage rate of 1 mg/l/hr (Table 6) as the source strength, which calculates to 357 mg/s, and an array of metrological (MET) conditions (Table 14, Scenario 1) that closely matched the conditions seen during leak testing (Figure 31). As a result of best-fit dimensions, model domain and wind field grid sizes were fixed at 500x500x75 m.

Neighboring infrastructure was limited to two student dormitories, approximately 20 m northwest of the fumigated house. House positioning and dimensions were modeled using Light Detection and Ranging (LiDAR) data retrieved from the United States Geological Service (USGS). Vegetative canopies and attenuation coefficients were not used due to sparse biomass. In light of the dilute nature of MB leaving the house and the very slight variations in terrain surrounding the house, elevation was not considered.

Table 14. QUIC Input Parameters

Scenario 1	Scenario 2
Wind speed: .44 m/s (calm)	Wind speed: 4 m/s
Wind angle: 328 °	Wind angle: 125 °
Release type: Continuous	Release type: Continuous
Source strength: 357 mg/s	Source strength: 357 mg/s
Source geometry: 22x14x4 (m)	Source geometry: 22x14x4 (m)
Sample height: 1.5 (m)	Sample height: 1.5 (m)

3.8.1 Scenario 1

MET conditions for Scenario 1 were retrieved from the Florida Automated Weather Network (FLREC) on 12/11/13 at 0400 hrs. Though the observed MET conditions were abnormal for this area, they allowed for a direct comparison of measurements (see Figure 31) taken at 0414 hrs on December 11th 2013, a period of very calm winds. Scenario 1 showed a small quantity of MB (ranging from 0.86 to 3.45 ppm) being emitted from the house. The horizontal dimension of the plume was seen to increase around the house and quickly dilute further downwind. Model plots show the gas diffusing over an area approximately 30 m southeast of the house. As a result of calm wind conditions, dilution affects were minimal. Near worst case concentration levels of MB, therefore, were predicted near the house. Model results in Figure 40 were correlated with air samples shown in Figures 31. It should be noted that even under these near worst case conditions the MB concentrations at the 30 feet standoff perimeter were less than 1 ppm, less than the OEL.

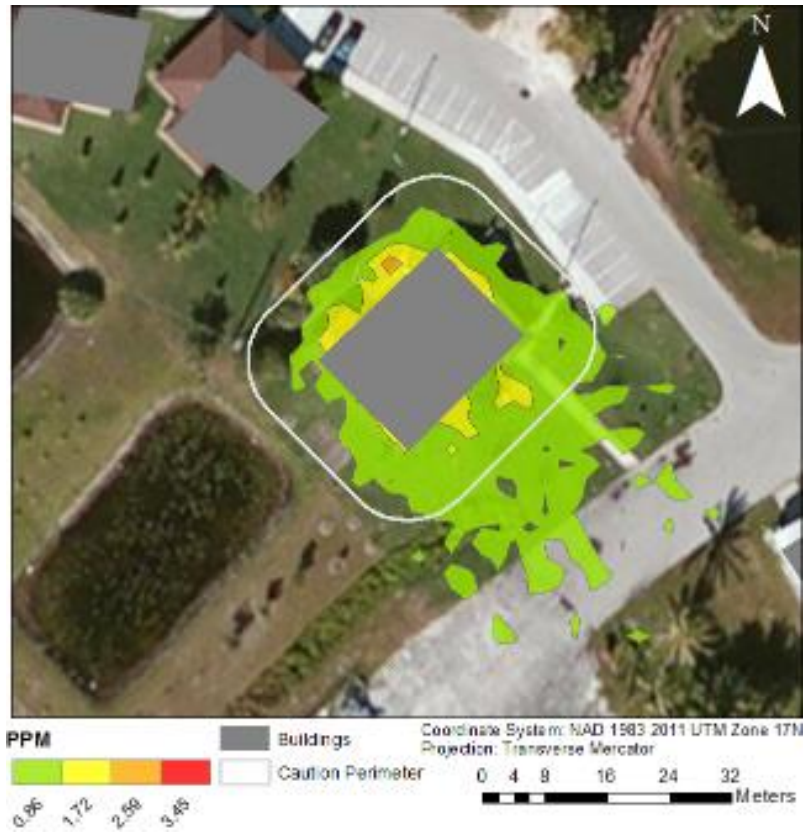


Figure 40. QUIC Model MB Concentration Results near the House during Fumigation

3.8.2 Scenario 2

MET conditions for Scenario 2 were derived by averaging weather observations retrieved from the Fort Lauderdale-Hollywood International Airport (AWS ID: 747830) between 12-9-13 – 12-11-13. The derived MET conditions were characteristic of those seen over the duration of the study. Scenario 2 results (Figure 41) show a dilute concentration of MB extending approximately 50 m northeast of the house. Lateral spreading is more pronounced due to steady wind speed of 4 m/s resulting in reduced MB concentrations. These measurements were correlated with collected ambient air monitoring data. Model plots showed a significant amount of building-induced turbulence near the student housing to the northwest. Although concentrations of MB were below any recommended exposure limits, in an effort to keep any exposures to MB as low as technically feasible, the decision to evacuate the inhabitants of these buildings was supported by the QUIC analysis using the prevailing winds in that location. The higher wind speeds of Scenario 2 increased dilution, resulting in lower MB concentrations in ambient air as compared to Scenario 1.

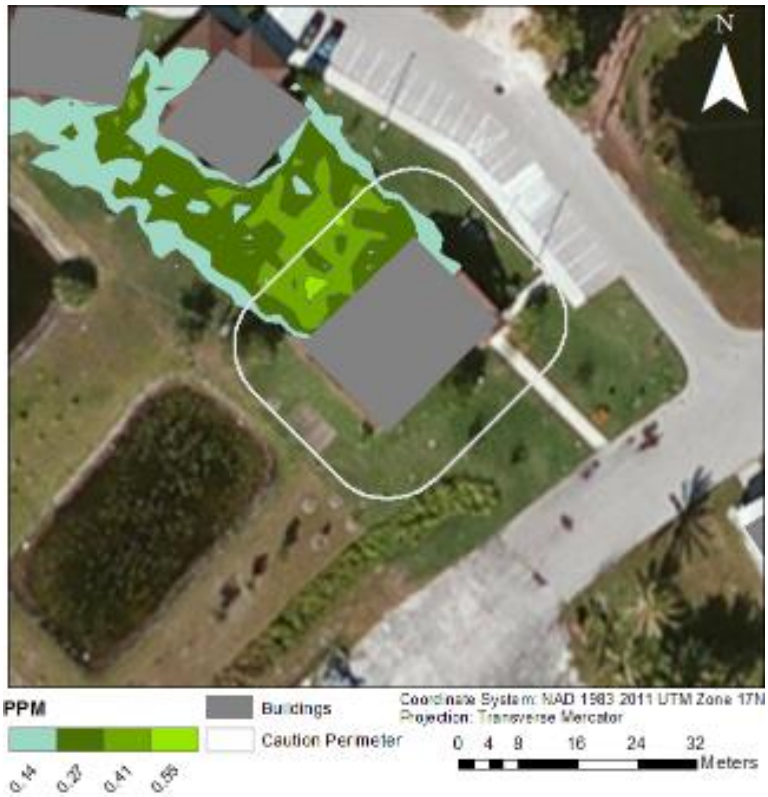


Figure 41. QUIC Scenario 2 Results

3.8.3 Modeling Discussion

Overall, QUIC was effective in predicting the dispersion of MB during fumigation activities as a function of gas emission levels from the house. Based on an emission rate of 360 mg/s, model predictions were commensurate with observed leak and ambient air monitoring data (Figure 31 and Figures in Appendix B). The resulting plots indicate a continuous release MB is expected to remain hazardous only very near the house if you were to stay there for prolonged periods of time during the fumigation. The following should be noted:

- Results from Scenario 1 were correlated with MB leak-detection readings taken on 12-11-13 at 0414 hrs (Figure 31).
- Results from Scenario 2 were correlated with ambient air monitoring results which were typically below the action level of MB during the entire fumigation.
- Although concentrations of MB were below the action level for scenario 2, pre-fumigation evacuation of inhabitants in nearby structures was a prudent precaution, eliminating all inhabitant MB exposure.
- QUIC successfully accounted for the turbulence phenomena of nearby buildings.
- Both scenarios support the use of the 20 to 30 feet caution perimeter CRZ.

The purpose of this modeling was to better understand the atmospheric dispersion of leaking MB as a result of fumigation activities. While no dispersion model can perfectly predict a real-world

outcome, the behavior of gaseous agents, such as MB, can generally be estimated. Based on the results of this modeling, QUIC can be considered a feasible planning tool for both small- and large-scale fumigation activities and may prove to be most beneficial in a building-rich urban setting.

3.9 House Entries

Although no entry was anticipated, two unexpected events occurred during the fumigation that required entry into the test house when concentrations were above 5 ppm. First, the MB fumigant shoot line burst early during the fumigation (fewer than 200 of the planned 700 lbs of MB needed to achieve the target concentration was released before the line burst), requiring two trained fumigation contractors to enter the house for 15 minutes while wearing SCBAs (EPA personnel remained ready with SCBAs as backup/rescue) to repair the shoot line. A second 30-minute entry into the test house occurred post fumigation, as MB levels were continuing to decrease by natural ventilation following the activated-carbon scrubbing, in order to retrieve the test coupons in a timely fashion (before tenting and fumigation crews entered the house).

EPA personnel wore personal breathing zone samplers while conducting certain tasks identified as having potential for elevated MB exposure. Site SOs collected these samplers and sent them for analysis. MB was not detected above the quantification limit on any personal samples, and exposure was determined to be below applicable OELs during these tasks.

Following final indoor aeration to achieve below 1ppm of MB (12 hours after initial passive aeration), the tarps, sand snakes, and clamps were removed from the house. All electronics and appliances were found to be operating normally. According to UF personnel, a transient residual odor common to MB fumigations lingered in the house for about four days.

4 Conclusions and Recommendations:

Fumigation with methyl bromide gas was effective for the inactivation of *Bacillus* spores when used at the following conditions:

- MB concentration of 212 mg/l
- Temperature of 27 °C
- Relative humidity of 75%

From the laboratory data and the time-series results of this study, a fumigation time of 36 hours is recommended. As a result of this study, we now have another tool in the *Ba* decontamination toolbox that increases our capacity to respond to a *Ba* release, especially in the case where high-value and/or corrosion-sensitive items are involved.

4.1 Objective 1, Conclusion

A QAPP was developed by a group of research and field professionals prior to the December 2013 field test. The QAPP included a detailed RAP, AAMP, and HASP. The SAP was incorporated into

the QAPP and was not a stand-alone document because, for this test, most of the sampling was covered by using BIs designed for this specific test. The documents were finalized and signed by EPA management in October prior to the December operational test. The HASP and AAMP were revised (Attachment 1 and 2, respectively), for future incident use, after the test to include key insights and lessons learned from the test.

4.2 Objective 2, Conclusion

The operational fumigation was conducted safely during the second week in December 2013. The activated carbon scrubber was set up December 6th-7th and connected to the house and tarps on the December 8th as the house was being tented. Humidification, heating, analytical and fumigation equipment were set up and biological indicator coupons were distributed throughout the house on December 9th. Fumigation began that afternoon and MB concentration inside the house reached the target at 2100 hours that day. MB concentration, temperature, and RH were monitored and maintained inside the house throughout the 48-hour fumigation.

4.3 Objective 3, Conclusion

Test coupons, 87 glass slides and 87 wood discs, inoculated with approximately 1 x 10^6 CFU per coupon non-pathogenic *B. anthracis* (Sterne) and placed in sterilized Tyvek® envelops were placed in 22 separate locations throughout the house prior to fumigation. Negative procedural blanks were included at each location. Positive and negative controls, 24 of each for both glass and wood were also taken to the site but did not go through the fumigation process. The evaluation of efficacy of the fumigation as measured by the deployment of coupons was successful. All the test coupons that went through the fumigation process were non-detect for spores.

4.4 Objective 4, Conclusion

An activated carbon scrubber system was connected to the house, used at the conclusion of the 48-hour fumigation, and monitored for breakthrough. The scrubber was effectively deployed and used to reduce the concentration of MB inside the house from approximately 55,000 ppm to below 150 ppm in 3.5 hours. Breakthrough was monitored and obtained for both carbon beds set up in series. Results are available for future scrubber design(s).

4.5 Objective 5, Conclusion

Ambient air monitoring was achieved by placing photoionization monitors at six stationary locations around the house. In addition, hand-held monitors with the same technology were used to leak test the tenting materials and to provide monitoring for locations not covered by the six stationary monitors. The monitors were effective for MB monitoring and provided a successful health protection measure for not only the on-site workers, but for offsite persons, as well. MB monitors detected small leaks near the tented house which directed leak reduction measures to be deployed, as needed. During leak detection, the MB concentration was observed

to dissipate quickly as the hand-held monitors were moved out and away from the tented house. Leak-reduction techniques abated leaks quickly after they were detected by air monitors.

4.6 Recommendations

Based on the lessons learned (Appendix A) during this fumigation field test, there were several recommendations that are listed here that have been incorporated into the revised HASP and AMMP.

- Coordinate communications among all on-site personnel. The performance of this fumigation test required multiple disciplines and several different teams (e.g., tarping, fumigation, exposure monitoring, scrubbing, and health and safety). Each team had different responsibilities, standard protocols and discipline-specific terminologies that needed to be understood across the disciplines in order for the operation to run successfully. Site management must construct the bridges between the multiple-disciplinary teams to assure that communication among teams is clear and accurate.
- In order to obtain and maintain the high humidity required during fumigation, as was required in this study, it may be important to: turn off the existing HVAC system in the house and add humidity to precondition the contents, prior to fumigation. Also, if there are large amounts of "dry" contents, some of the contents may need to be removed prior to fumigation so that the efficacious humidity can be reached and maintained.
- There are times when purchasing or leasing the correct equipment for the job is more advantageous than "making something work"; instead of using an extension to the end of the shooting hose, try to acquire longer reinforced high pressure shooting hoses since they can be made to custom lengths with no extension needed (e.g., A 40-foot hose would have cost approximately $450.00; and would have been well worth the cost).
- MB may have leaked at a higher rate during and directly after gas was added to the house; this would be caused by the increased pressure resulting from this volume of gas being added to the system. When adding MB into the house, therefore, consider removing a similar volume of air out of the house through the carbon scrubber (low flow rates should be used to reduce stresses on tent seams). This should be helpful in reducing subsequent leakage caused by added pressure inside the house.
- It is important that all duct work connections should both go together and seal easily. To ensure this, require in the procurement specifications, that all duct-work be pre-fit from the manufacturer/leasing company prior to shipment.
- To achieve better containment of the MB, use quality leak-resistant valves between the house and the scrubber duct. The simple sheet-metal blast gate used during the fumigation test allowed MB to leak out of the house into the scrubber duct. The use of a sealing gate- or ball-valve would help contain fumigant.
- Large scrubber vessels require using a more-expensive, heavy-capacity fork-lift. Smaller scrubber vessels placed in series could be used during future fumigation efforts, reducing the fork-lift requirements.

- There was a potential hazard to workers performing tasks near the tent material when the scrubber blower was turned on (tent material is suddenly pulled in by the blowers). First, open the make-up air gate, then open the blast gate to the scrubber while simultaneously tuning on the scrubber blower (the gate for make-up air must be open before or at the same time as the blower is powered on).
- Although industry standards recommend loose fitting clothing when working around liquid MB, responders should be prepared for Level "A" entries with fully encapsulated suits rated for protection against MB, as prescribed by the site Industrial Hygienist / SO or Incident Commander (IC) in the event that an entry would be necessary when fumigation was ongoing. Both an entry team, and a rescue team are required.
- As seen in Figure 42 below, grass kill was the result of constant MB diffusion through the ground-seal apron. Some diffusion plume trails are seen as brown grass extending beyond the ground seal apron. Similar diffusion must have also occurred through the entire raised surface resulting in loss of some 200 lbs of MB. The new aluminum-layered Insul-tarp® planned for a future fumigation should reduce diffusive loss greatly. As noted in the report, the other important loss of MB was related to ducting connections from the house to the scrubbers and increased pressure from adding gas to the enclosure.

Figure 42. Grass Kill as a Result of MB Diffusion Through the Ground-seal Apron.

- As with any activity involving potential exposure to hazardous agents, personnel who enter the EZ or CRZ must be included in an occupational medical surveillance program. Baseline and post exposure bromide biological monitoring should be considered as advised by the employees' occupational health physician.
- Identify MB-specific monitors to utilize in addition to the non-specific PID. As an example: Develop MB key for Single Point Monitors.

- A method to plug monitoring lines was needed when they were not attached to the fumiscope, as the test team discovered MB leaking back out of the lines. These ¼" polyethylene lines could be plugged with a cap or similar objects.
- Planning for demobilization after performing a field study is as important as planning for the test, itself; a person familiar with International Air Transport Association shipping guidelines needs to assist with labeling, shipping, and coordinating the return of: unused gases, scrubber vessels, etc.
- Pre-2005 MB was purchased for this test. MB purchased for use under current exemptions is much less expensive. During a response to a national incident an emergency exemption would be requested and, if granted, would allow the procurement of MB at current market rates. To control collateral damage due to corrosion, MB without chloropicrin should be used. In addition, research looking at the recovery of MB from activated carbon for reuse is recommended.

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Appendix A. Overall Operation of the Project: Lessons Learned

At the conclusion of the project, the test team members met to capture all important lessons learned during the project. The goal was to document the onsite observations and identify areas of potential improvement. The following bullets capture those important findings:

- Coordinate communications among all on-site personnel. The performance of this fumigation test required multiple disciplines and several different teams (e.g., tarping, fumigation, exposure monitoring, scrubbing, and health and safety). Each team had different responsibilities, standard protocols and discipline-specific terminologies that needed to be understood across the disciplines in order for the operation to run successfully. Site management must construct the bridges between the multiple-disciplinary teams to assure that communication among teams is clear and accurate.
- Initial collection of temporal progression coupons should be initiated earlier during the fumigation process. By the time we collected the first set of temporal coupons, 16 hours into the fumigation, the efficacy of the fumigation process was almost complete. Valuable data was missed by not taking temporal coupons earlier in the fumigation.
- Though it did not happen during this project, there was a concern that the humidifiers might run out of water during the fumigation. In order to obtain and maintain the high humidity required during fumigation, as was required in this study, it may be important to: turn off the existing HVAC system in the house and add humidity to precondition the contents, prior to fumigation. If there are large amounts of "dry" contents, some of the contents may need to be removed prior to fumigation so that the efficacious humidity can be reached and maintained. Additionally, a refill system needs to be devised for the humidifiers or larger reservoirs of water could be developed for the humidifiers used.

Tenting and Shooting

- Pre-2005 MB was purchased for this test. MB purchased for use under current exemptions is much less expensive. During a response to a national incident an emergency exemption would be requested, and if granted, would allow the procurement of MB at current market rates. To control collateral damage due to corrosion, MB without chloropicrin should be used.
- Heat exchanger operation:
    - During the initial injection of MB into the house it was determined that the heat exchanger inlet/outlet ports were incorrectly plumbed. Ensure that the temp gauge and inlet/outlet ports are installed correctly prior to initiation of MB shooting.
    - Test the heating system ahead of time to ensure proper operation.
    - In order to reduce the time needed to get to the target MB concentration, multiple heat exchangers could be used.

- It was difficult to monitor the propane heater flame during operation. If propane heat exchangers are used during future tests, placing a mirror underneath the unit will allow one to more easily monitor the propane flame from a standing positon.
- Since liquid MB can damage flooring and other objects, plan for placing protective material(s) under the shooting lines to reduce damage in the event that a malfunction occurs.
- A shoot line extension was used to reach the release point inside the house. That extension failed early in the fumigation process. There are times when purchasing or leasing the correct equipment for the job is more advantageous than "making something work"; instead of using an extension to the end of the shooting hose, try to acquire longer reinforced high pressure shooting hoses since they can be made to custom lengths with no extension needed (e.g., A 40-foot hose would have cost approximately $450.00; and would have been well worth the cost).

- It appears that the humidity is affected by the injection of additional MB gas into the house. This is due to the lack of water vapor in the MB gas which is displacing and warming humidified air. When injecting MB into the house, it is important to closely monitor the humidity and add humidity as needed.
- Most of the MB leaks seemed to occur directly after gas was added to the house; this could be due to the increased pressure resulting from this volume of gas being added to the system. When adding MB into the house, therefore, consider removing a similar volume of air out of the house through the carbon scrubber to balance the pressure. This should reduce subsequent leakage caused by added pressure inside the house.
- During tenting the placement of shoot lines and extraction points for the temporal coupons was located and re-located. To avoid re-establishing tenting seals, establish shooting locations ahead of tenting the house.
- If the truck that contains the cylinder scale cannot be moved adjacent to the house being fumigated (these truck usually contains an onboard scale for measuring fumigant used), a large heavy-duty digital floor scale can be used to measure loss of weight in MB cylinders during fumigant introduction.

Scrubbing & Aeration

- Scrubber duct work connecting house, carbon beds, blower, and stack did not easily fit together. It is important that all duct work connections should both go together and seal easily. To ensure this, require in the procurement specifications, that all duct-work be pre-fit from the manufacturer/leasing company prior to shipment.
- The simple sheet-metal blast gate used during the fumigation test allowed MB to leak out of the house into the scrubber duct. To achieve better containment of the MB, use quality leak-resistant valves between the house and the scrubber duct.
- Large scrubber vessels require using a more-expensive, heavy-capacity fork-lift; while smaller scrubber vessels placed in series could be used during future fumigation efforts.

- Scrubber system set up:
    - Large-diameter flexible ducting was difficult to install because it was heavy. For ease of setup, recommend using a smaller ducting and connections.
    - Caulking was very effective at stopping leaks; however, required a lot of caulk that did not dry for several days. Recommend using better fitting connections.
    - Galvanized metal should be smooth to allow duct to slide over with little effort. Welded joints caused problems with installing the rubber flexible ducting. Recommend using easy to connect ducting with tapered joints to allow the duct to slide on easily.
    - The galvanized band clamps were difficult to use. Recommend using ratchet clamps in place of the band clamps.
- To reduce air-flow losses and reduce stress at joint connections, recommend that the blower and scrubber vessels be setup as close as possible in a right triangle so that the inlet and outlet ports align. Use as much as possible: short distances, straight runs, and smooth duct to connect the scrubber components.
- Due to limited resources, the scrubber exhaust stack was not monitored continuously for breakthrough. Add resources to monitor the stack continuously or take grab samples using a Suma canister and analyze these samples later.
- There were some leaks noted around tent penetration including the makeup air inlet port. Need a better connection around the tent penetration. Molding clay could be used to seal ports passing under the tarp and other potential leaks.
- There is a potential hazard to workers performing tasks near the tent material when the scrubber blower is initially started. The tent material is suddenly pulled in as the scrubber blower is activated. To reduce this hazard the scrubber start up sequence should be: first open the makeup air-inlet port, then turn on the scrubber blower and at the same time open the blast gate to the scrubber (the port for make-up air must be open before or at the same time as the blower is powered on).
- To increase the effectiveness of the carbon scrubber, reduce the scrubber blower flow rate, this allows MB to adsorb more effectively onto the carbon.
- EVOH tarp material is very soft and several tears were found where the clips pinched a hole. Recommend using soft tip clips on all connections, including for the outer tarp because soft tip clips were used for the inner tarp but hard tips for outer tarp may have caused this damage.
- Scrubber vessels cannot be shipped back to the vendor immediately after project. Carbon samples must first be analyzed to assure hazardous materials are not trapped on the carbon. Add time to project schedule for carbon samples to be shipped, analyzed, and the system authorized for return before the scrubber system can be picked up.

Safety

- Need to plan for proper PPE when entering a house with MB present.
    - Site safety plan noted no entries would occur in the house until ambient concentrations were 5 ppm or less. On two occasions, it was necessary to enter at higher concentrations: 1) distribution line break, 2) retrieval of coupons prior to removing of tarp.
    - Future plans should address unanticipated entry.
    - The Tychem QC hooded suits on site have not been tested against MB. An appropriate number of MB Level-A suits should be on site prior to fumigation.
    - Although industry standards recommend loose fitting clothing when working around MB, responders should be prepared for Level "A" entries with fully encapsulated suits rated for protection against MB, as prescribed by the site Industrial Hygienist / Safety Officer or Incident Commander (IC) in the event that an entry would be necessary when fumigation was ongoing. Both an entry team, and a rescue team are required.
- As with any activity involving potential exposure to hazardous agents, personnel who enter the EZ or CRZ must be included in an occupational medical surveillance program. Baseline and post exposure bromide biological monitoring should be considered as advised by the employees' occupational health physician.

Perimeter Air Monitoring

- Area RAE monitoring stations were effective in detecting low level MB concentrations. As leaks occurred, the AreaRAE units often detected small temporary increases that correlated to a leak on that side of the tent.
- Handheld PID units were effective for pinpointing leaks along the tent. Concentrations often increased rapidly several inches from the tent (versus a slow steady increase as you got near the tent material).
- The RDA Fumiscopes and VIPER were not synchronized together, this should be done.
- The ambient air temperature and RH readings (or other MET data) with ambient air monitoring station was not connected to the VIPER network. Connect MET data to VIPER system for central collection of all data.
- The PIDs used at this site are not MB specific. Thus, it is not known if the PID response is from MB or other VOCs. Identify MB-specific monitors to utilize in addition to the non-specific PID. As an example: Develop MB key for Single Point Monitors.
- It was difficult to match up event notes and observations with VIPER data. Need a way to add written observation, comments, and event markers to VIPER database file along

with AAMP data – time stamped. Be systematic about capturing all observational data for correlation with instrument response.

- Some leak detection and routine collection of hand-held monitoring data was not recorded. Need to have a schedule for leak detection testing and standard form so uniform results may be recorded by different teams.
- There were ambient air monitoring false positives do to "hot box" and high humidity. Work on the monitoring system to reduce and illuminate false positives.

Interior Monitoring

- A method to plug/cap the monitoring lines was needed when they were not attached to the fumiscope, as the test team discovered, MB leaking back out of the uncapped lines. These ¼" polyethylene lines could be plugged with a cap or similar object (painters tap is not an effective plug).
- Collect air samples inside the house to see if any breakdown chemicals from foams and rubbers can be identified.
- Need a minimum of two portable monitoring devices and one back up unit.
- Setup a monitoring schedule, when samples should be taken and recorded.
- Monitoring station needs to have sufficient lighting and seating.
- Instruments need to be calibrated per manufacturer's recommendations and documentation kept with the instruments.

Other

- Approximately one medium dumpster (5 yards) of waste was produced during the entire project. Most of waste was used food and drink containers from on-site personnel. Other waste included; plastic wrapping, cardboard tubing, and plastic monitoring lines.
- Pallet strapping tools are needed for shipping scrubber parts back to the rental company.
- Planning for demobilization after performing a field study is as important as planning for the test itself; a person familiar with International Air Transport Association shipping guidelines needs to assist with labeling, shipping, and coordinating the return of: unused gases, scrubber vessels, and activated carbon samples from the scrubber.
- Compressed gas cylinder pick-up should be arranged in advance and may be difficult to ship from remote locations via common carrier.

Appendix B. Ambient Air Monitoring Figures

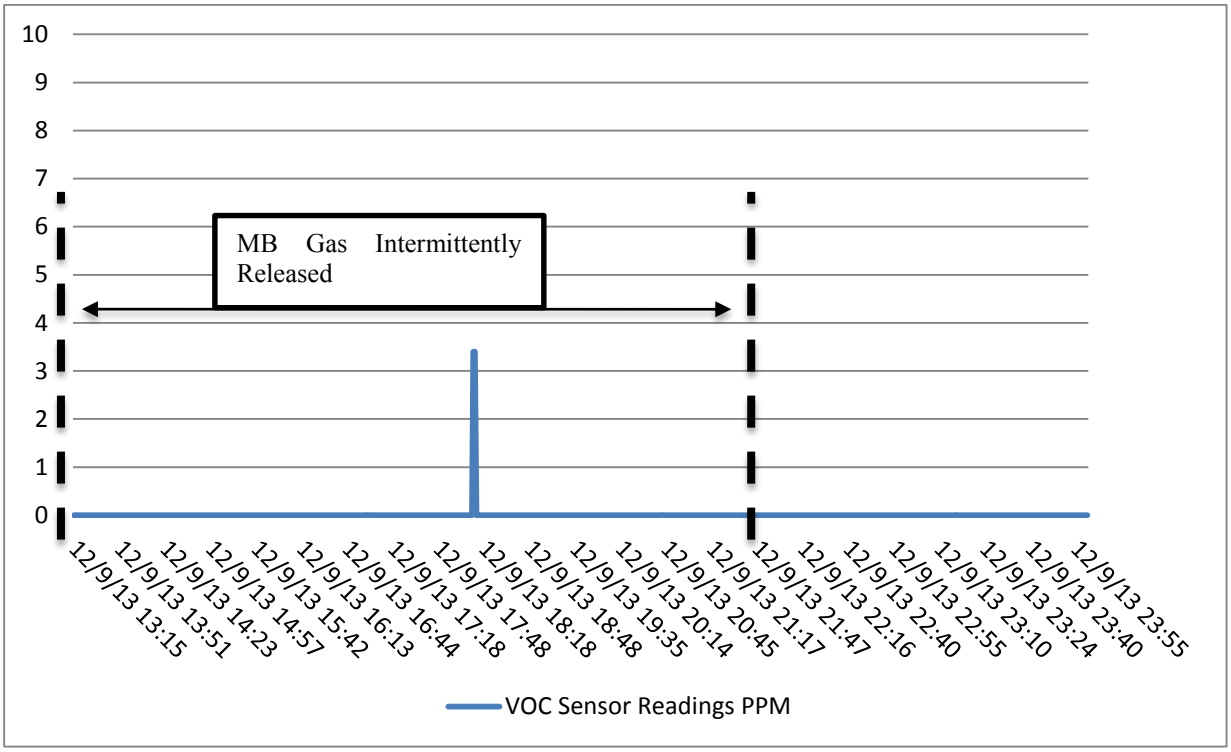


Figure B- 1. VOC Data from Location 101 LINC 78, 12/9/13

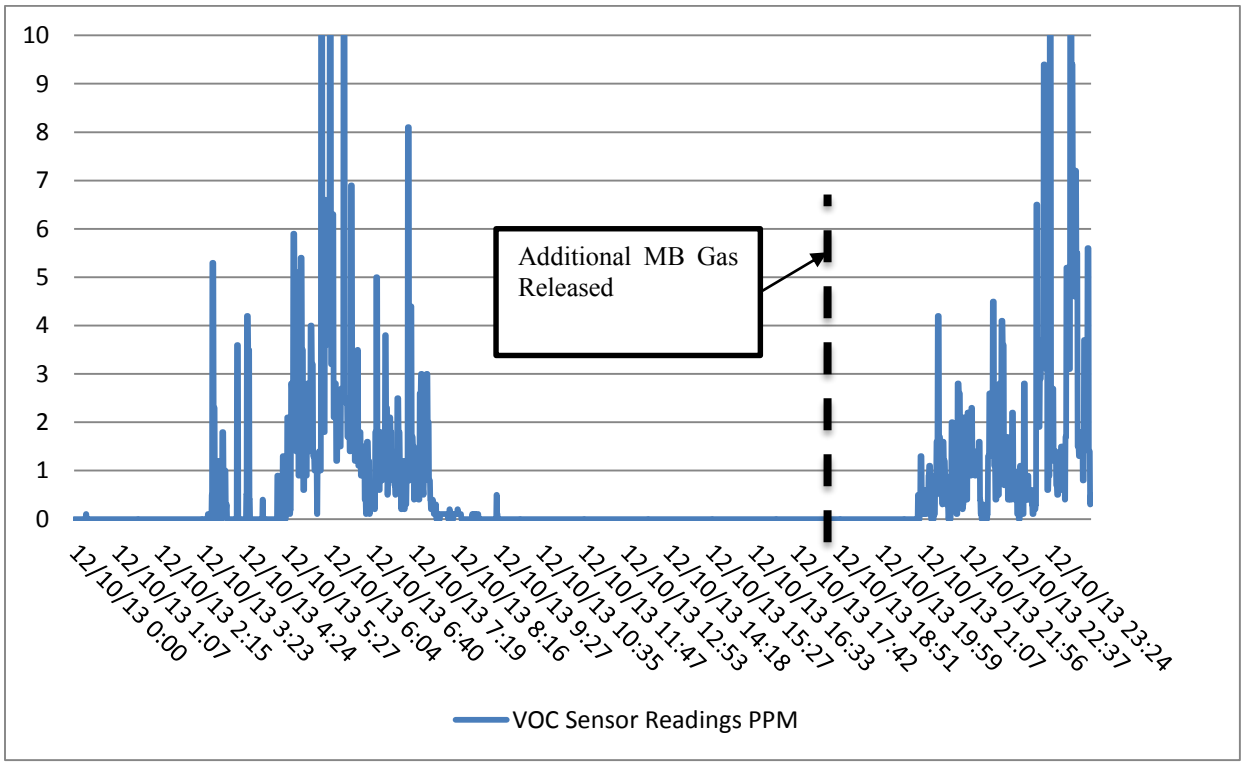
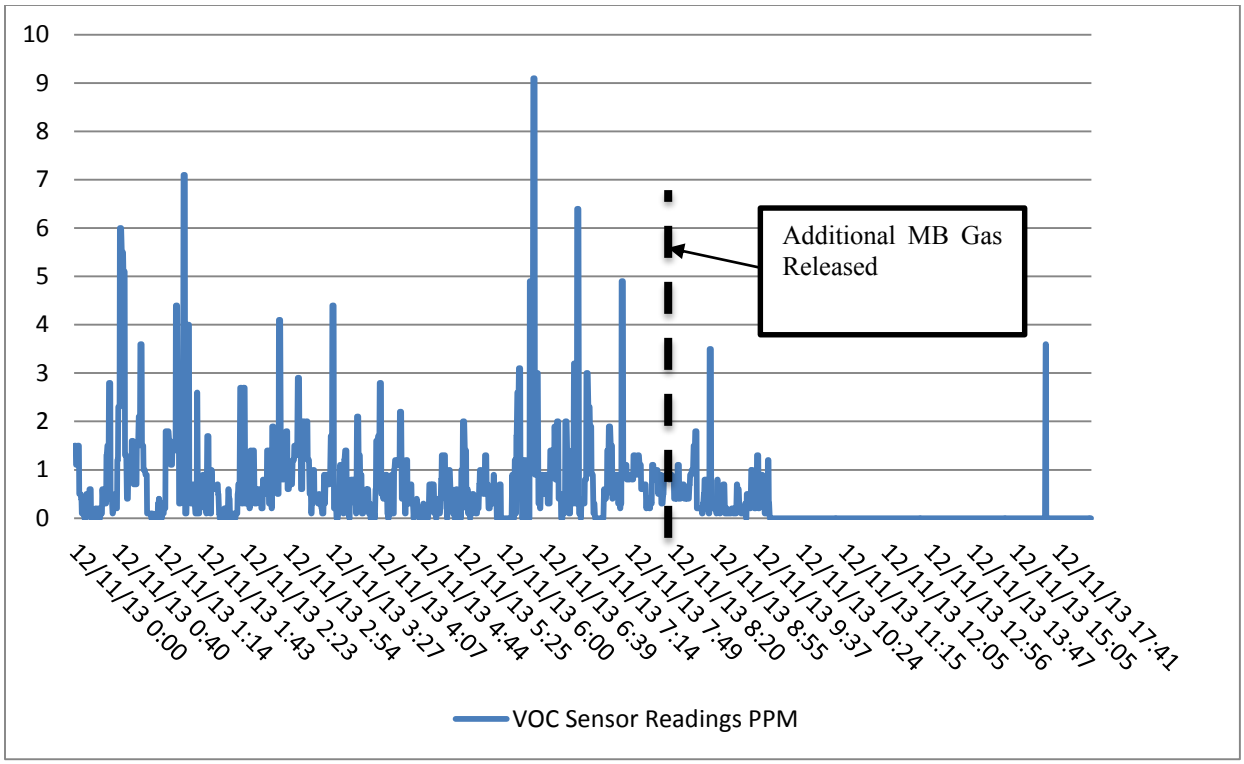


Figure B- 2. VOC Data from Location 101 LINC 78, 12/10/13



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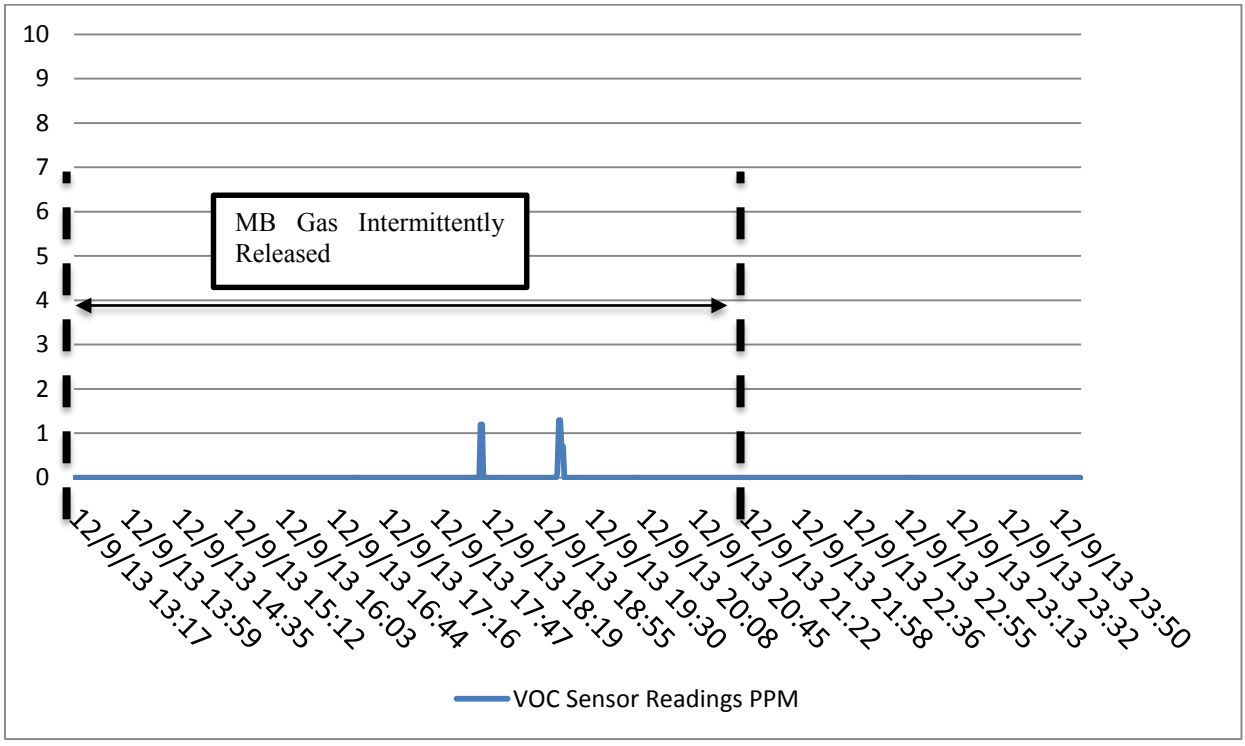


Figure B- 4. VOC Data from Location 102 LINC 109, 12/9/13

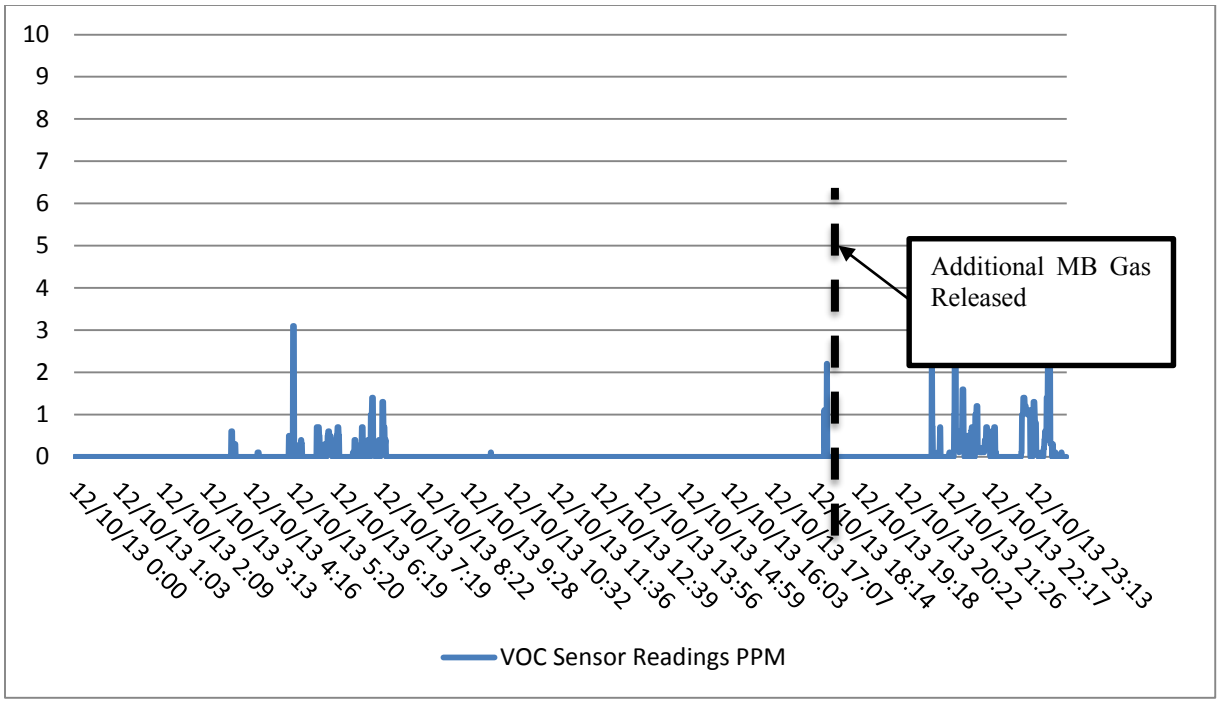


Figure B- 5. VOC Data from Location 102 LINC 109, 12/10/13

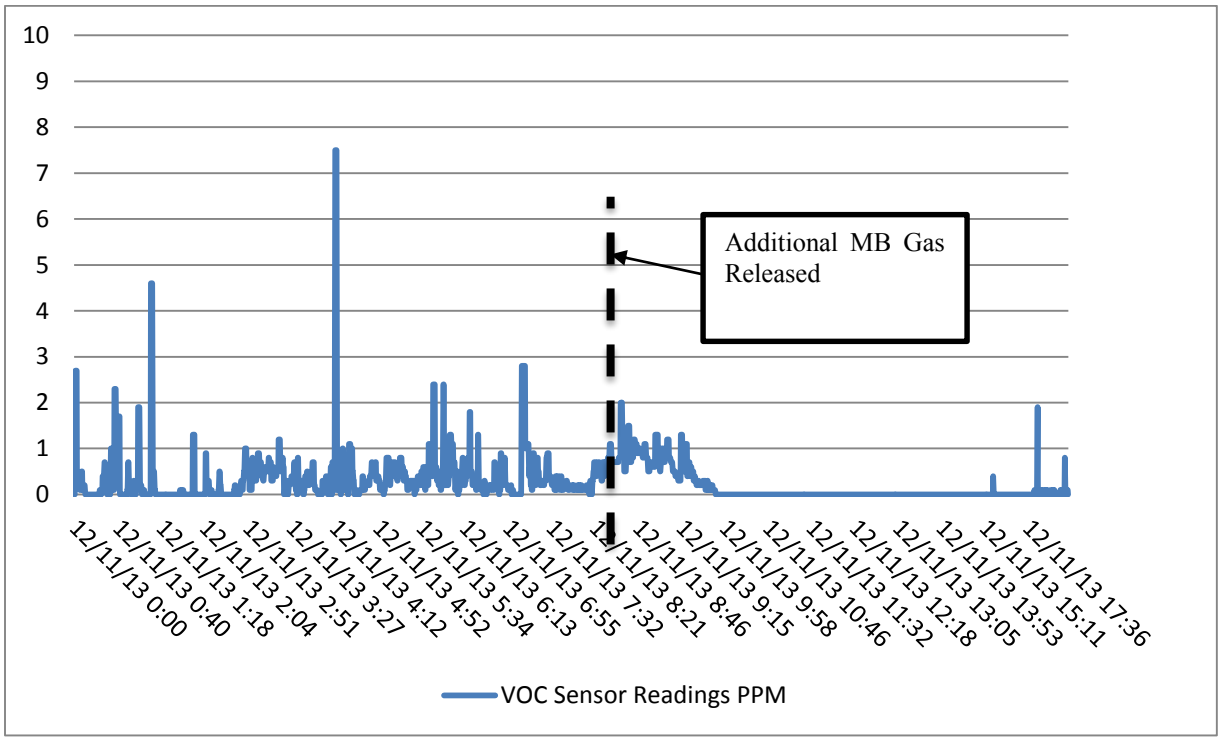


Figure B- 6. VOC Data from Location 102 LINC 109, 12/11/13

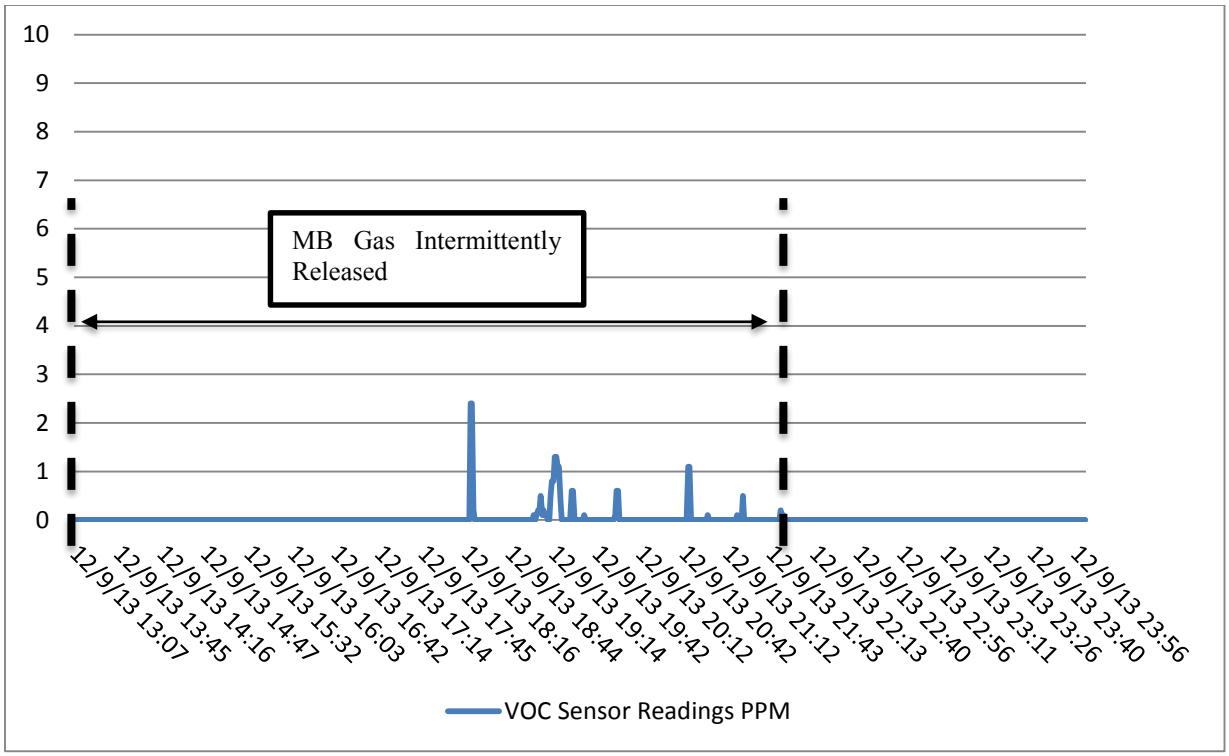
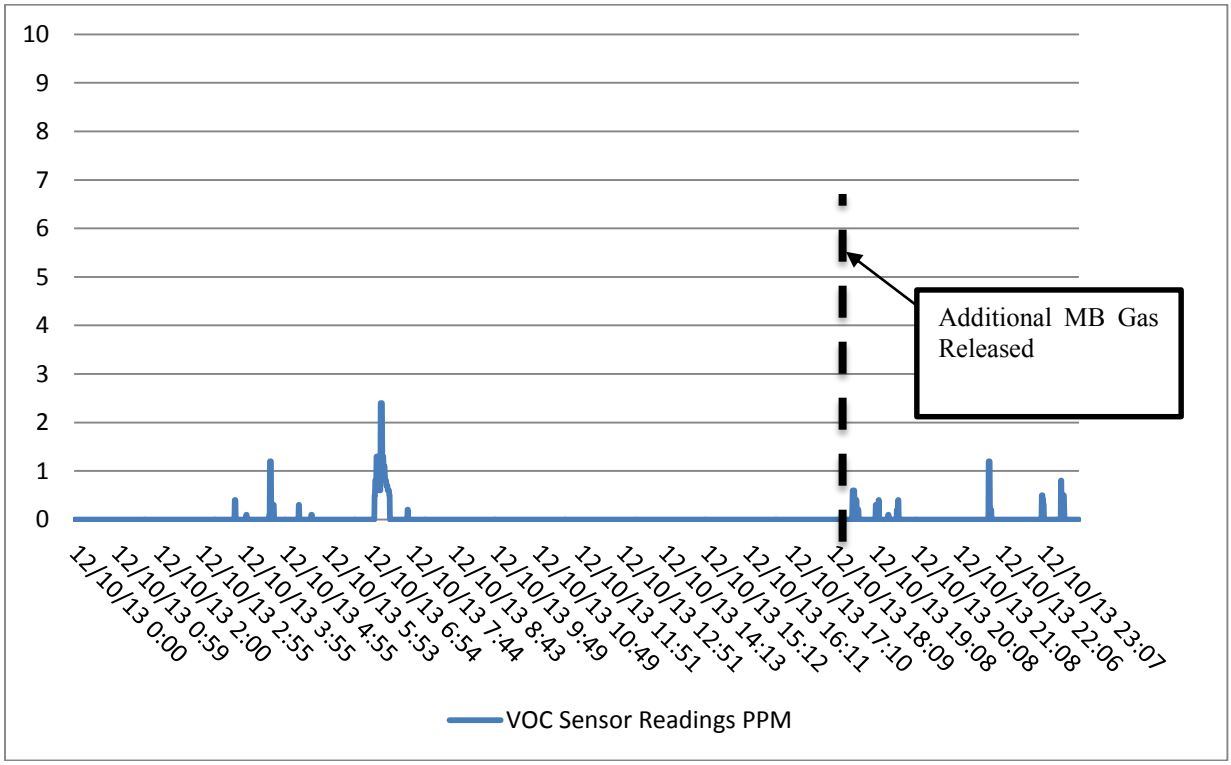


Figure B- 7. VOC Data from Location 103 LINC 76, 12/9/13



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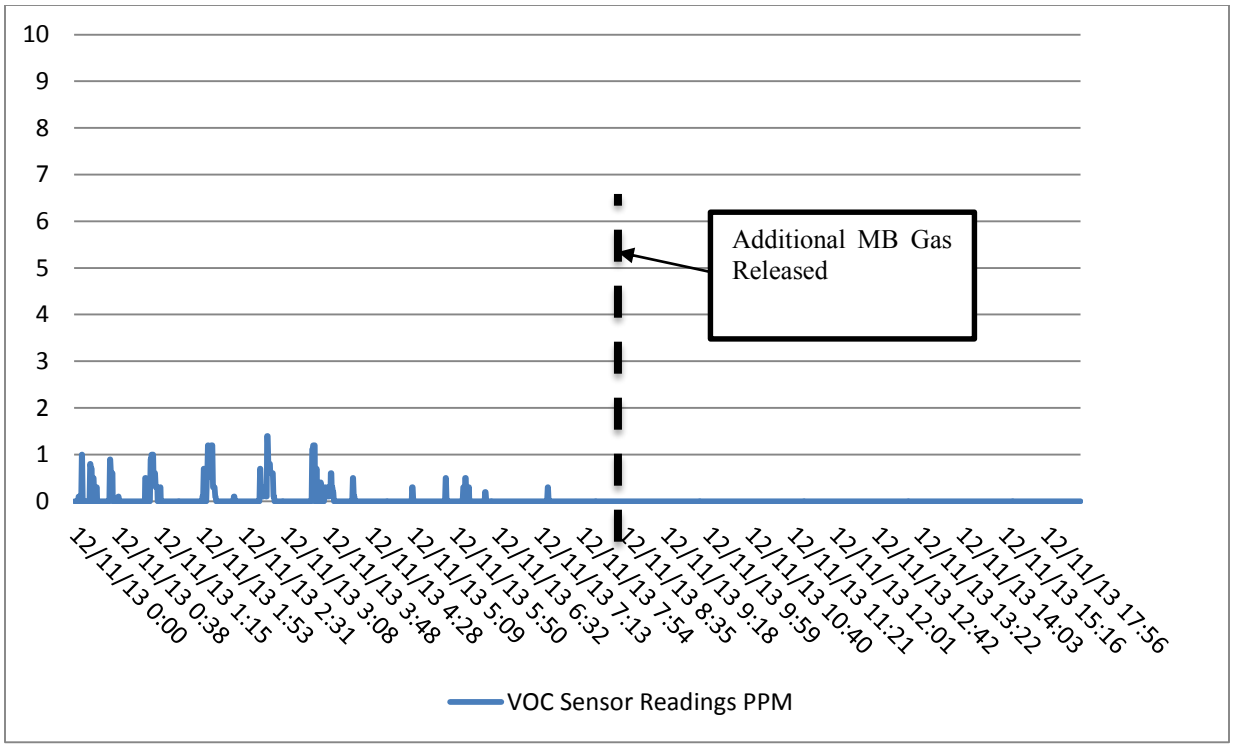

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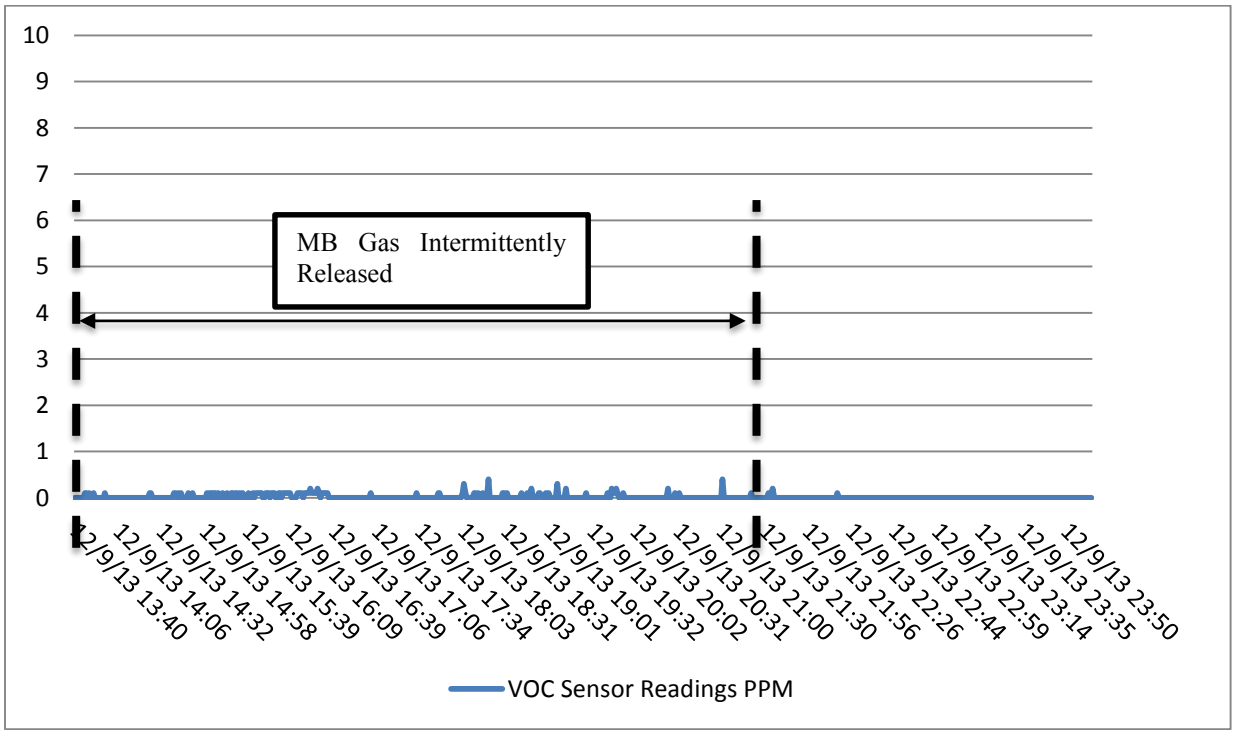

Figure B- 10. VOC Data from Location 104 LINC 33, 12/9/13

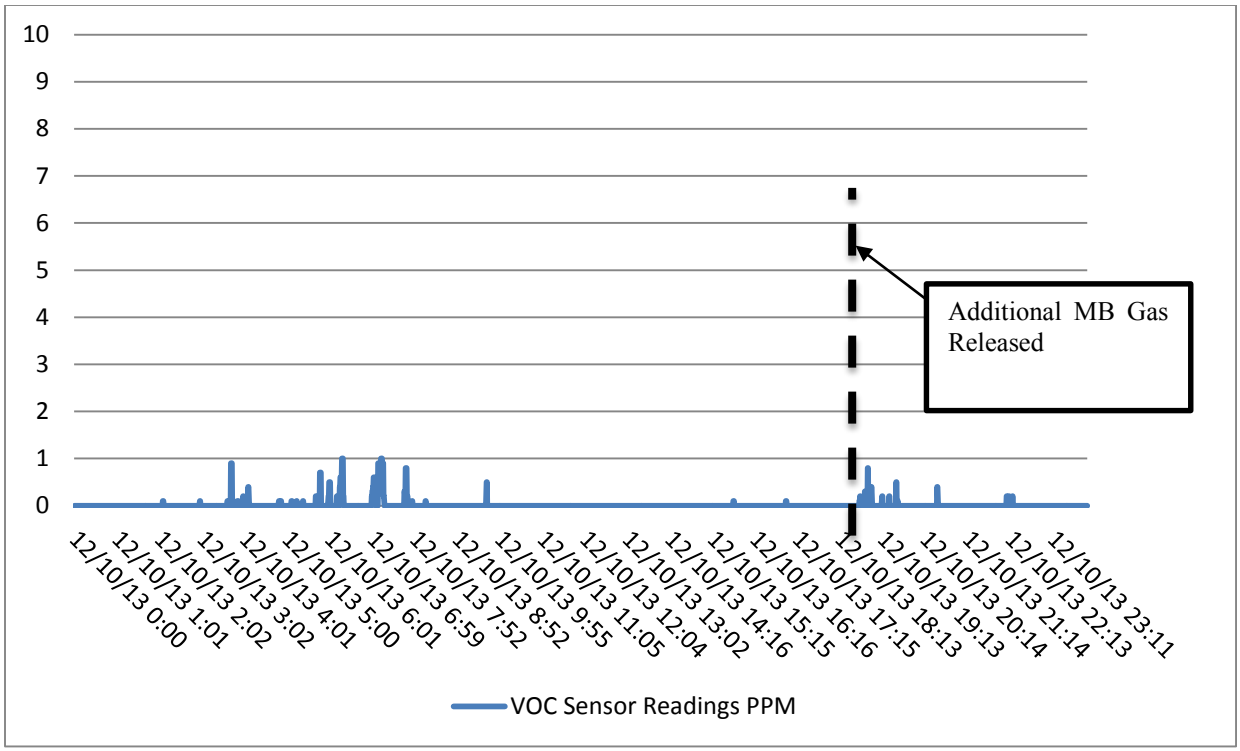

Figure B- 11. VOC Data from Location 104 LINC 33, 12/10/13

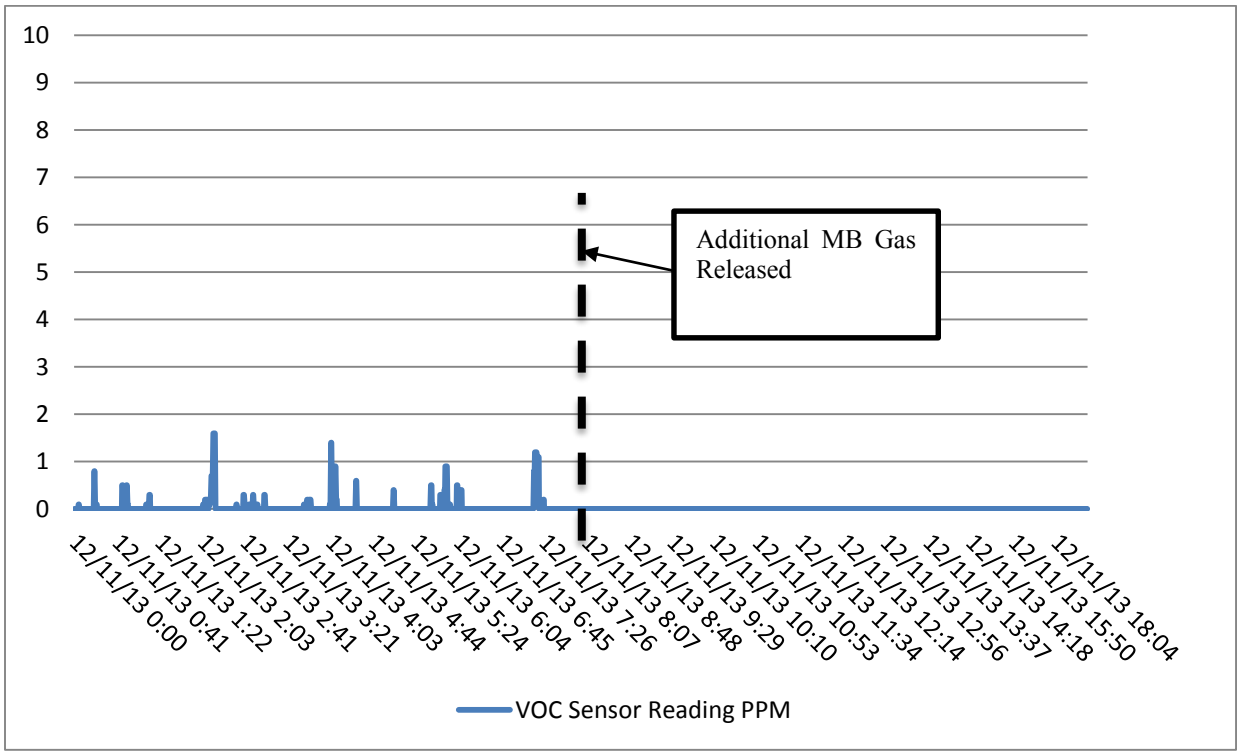

Figure B- 12. VOC Data from Location 104 LINC 33, 12/11/13

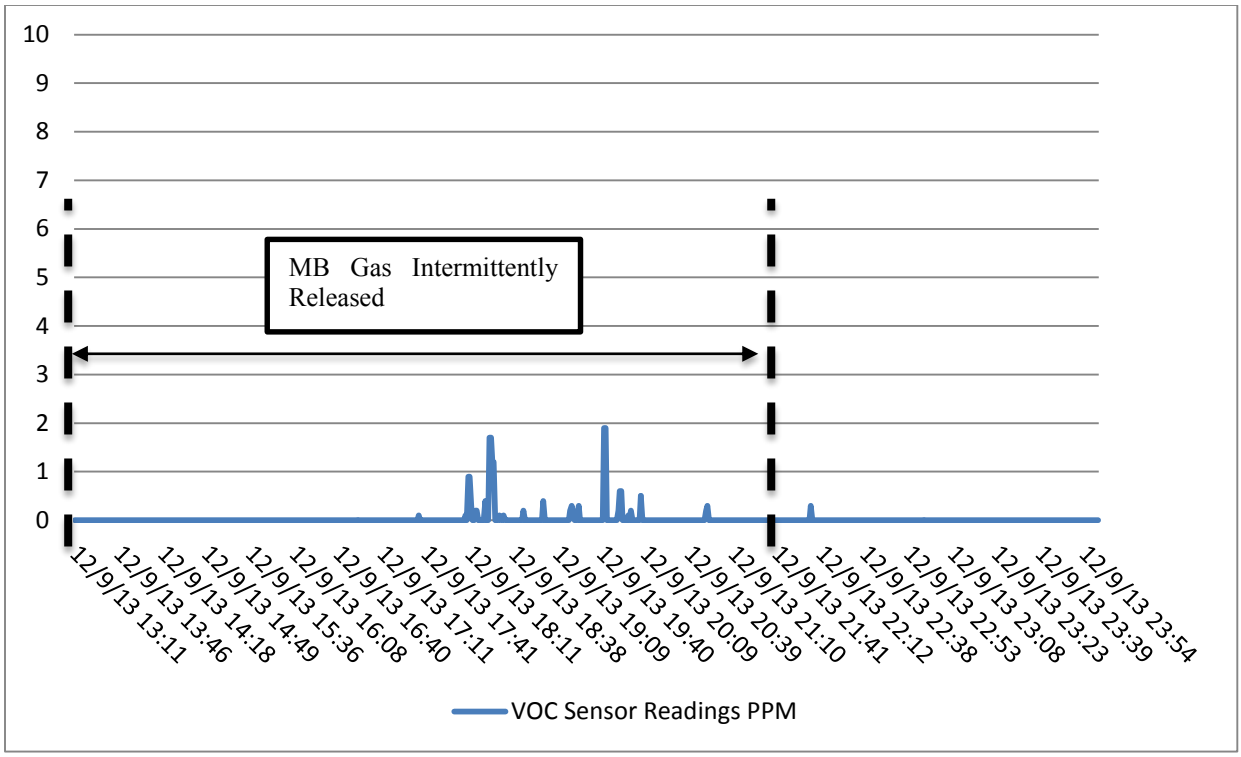

Figure B- 13. VOC Data from Location 105 LINC 80, 12/9/13

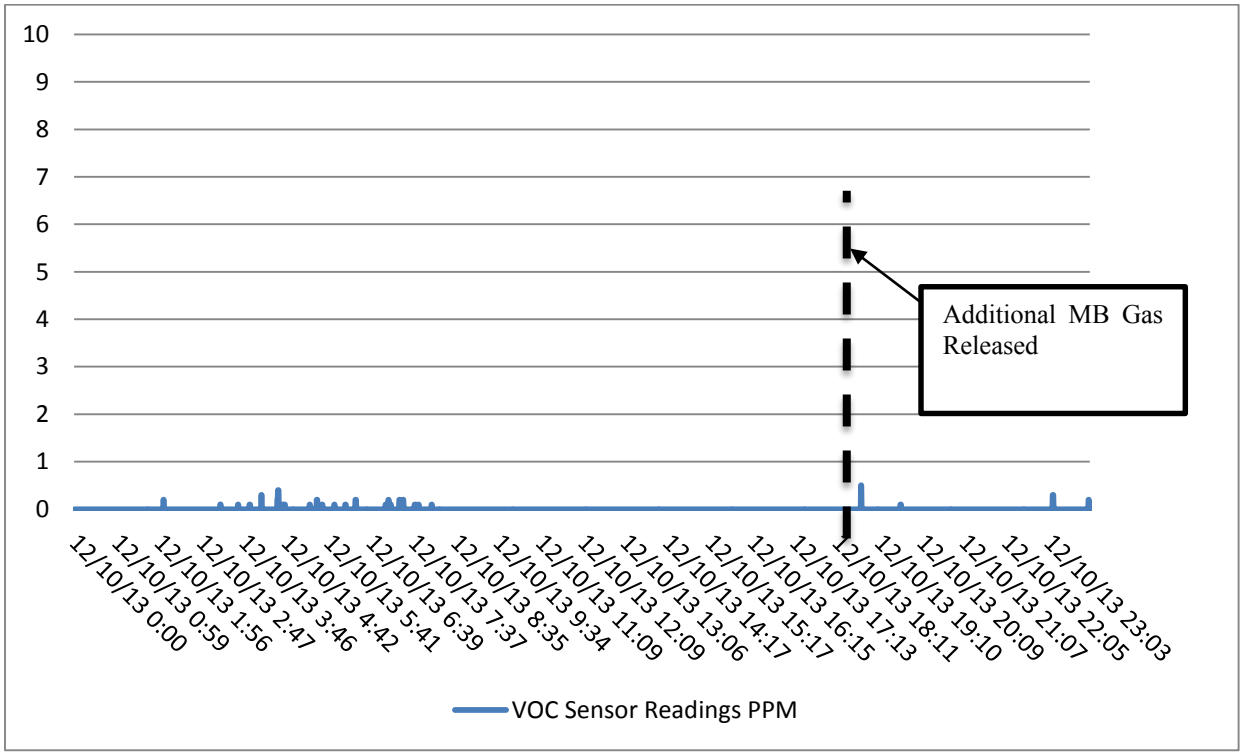

Figure B- 14. VOC Data from Location 105 LINC 80, 12/10/13

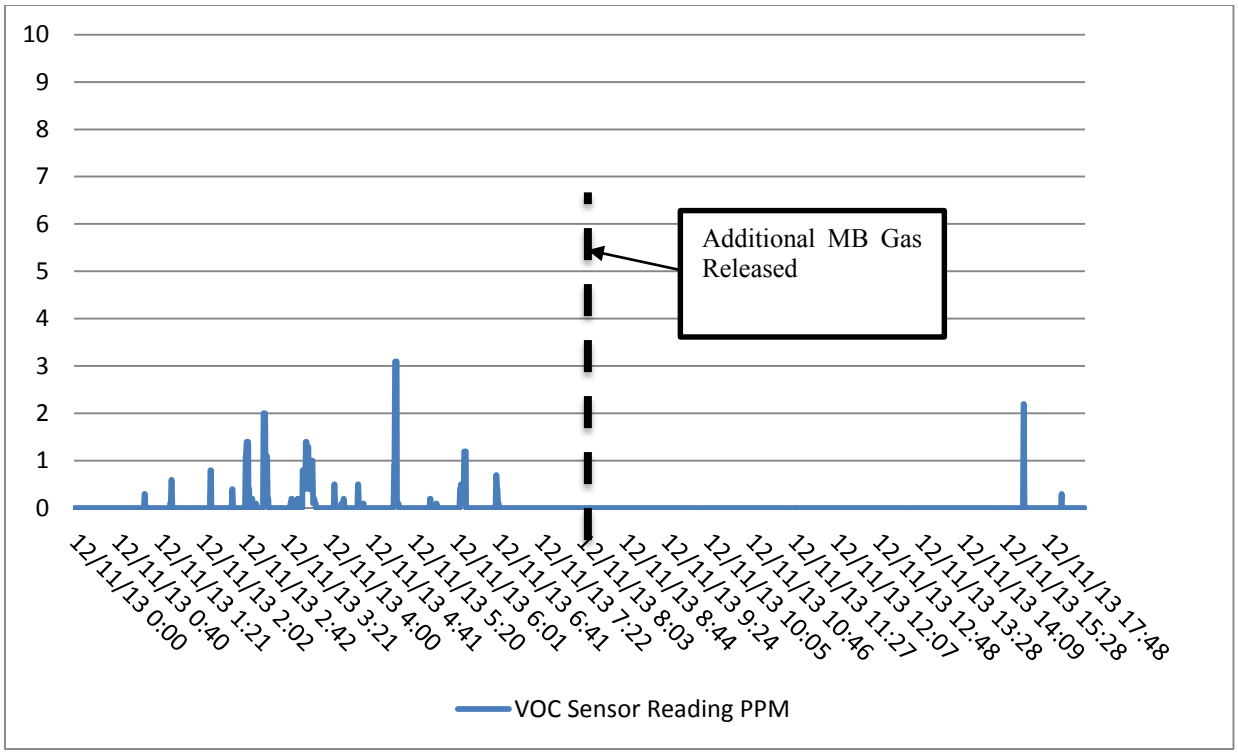

Figure B- 15. VOC Data from Location 105 LINC 80, 12/11/13

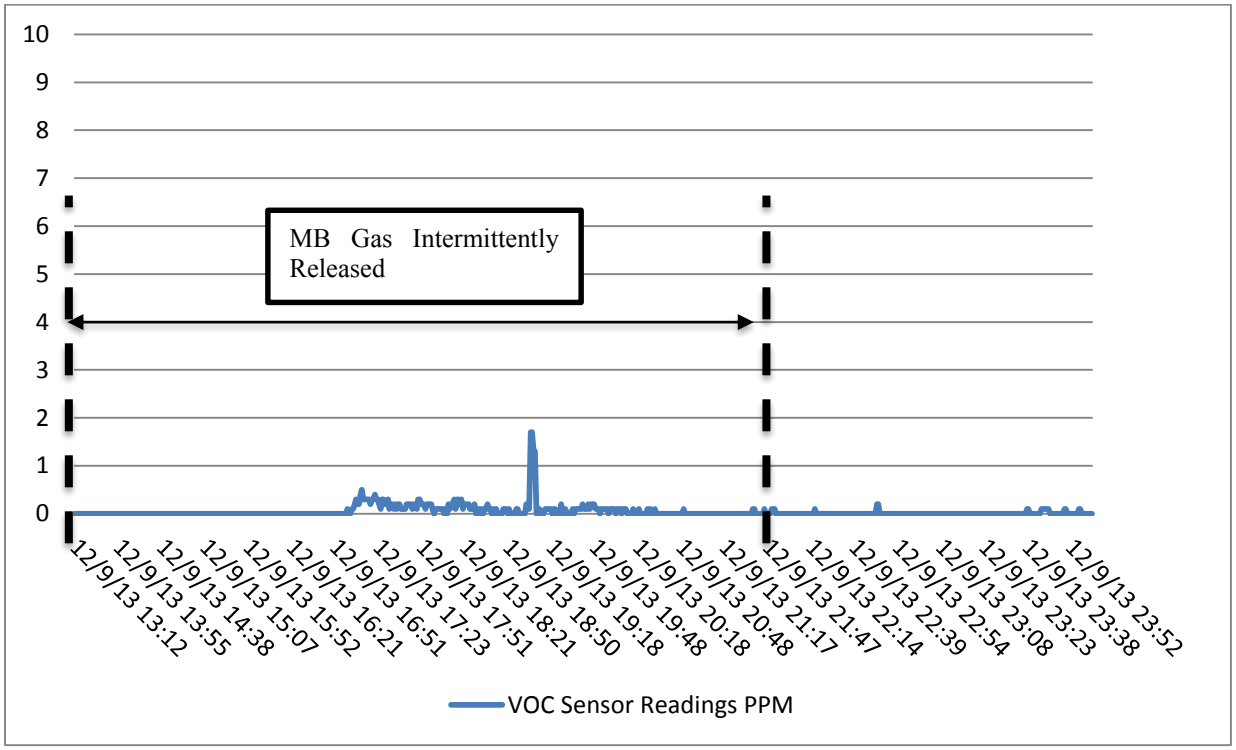

Figure B- 16. VOC Data from Location 106 LINC 42, 12/9/13

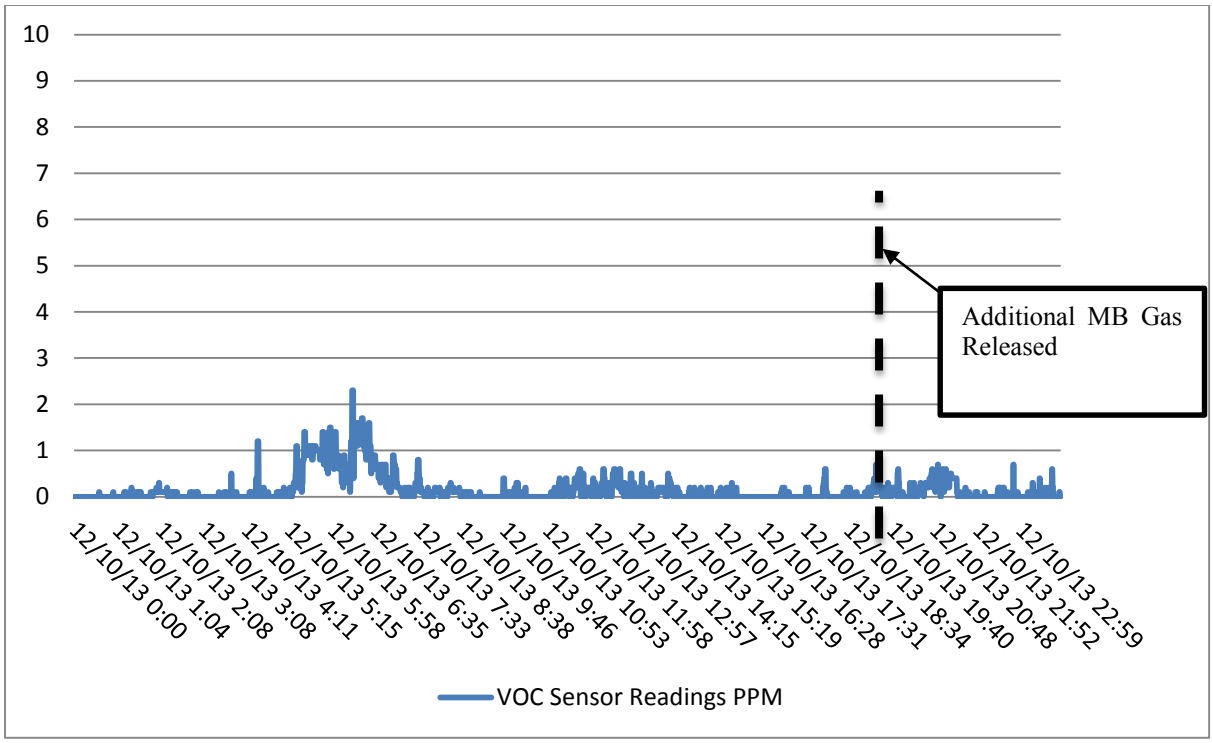

Figure B- 17. VOC Data from Location 106 LINC 42, 12/10/13

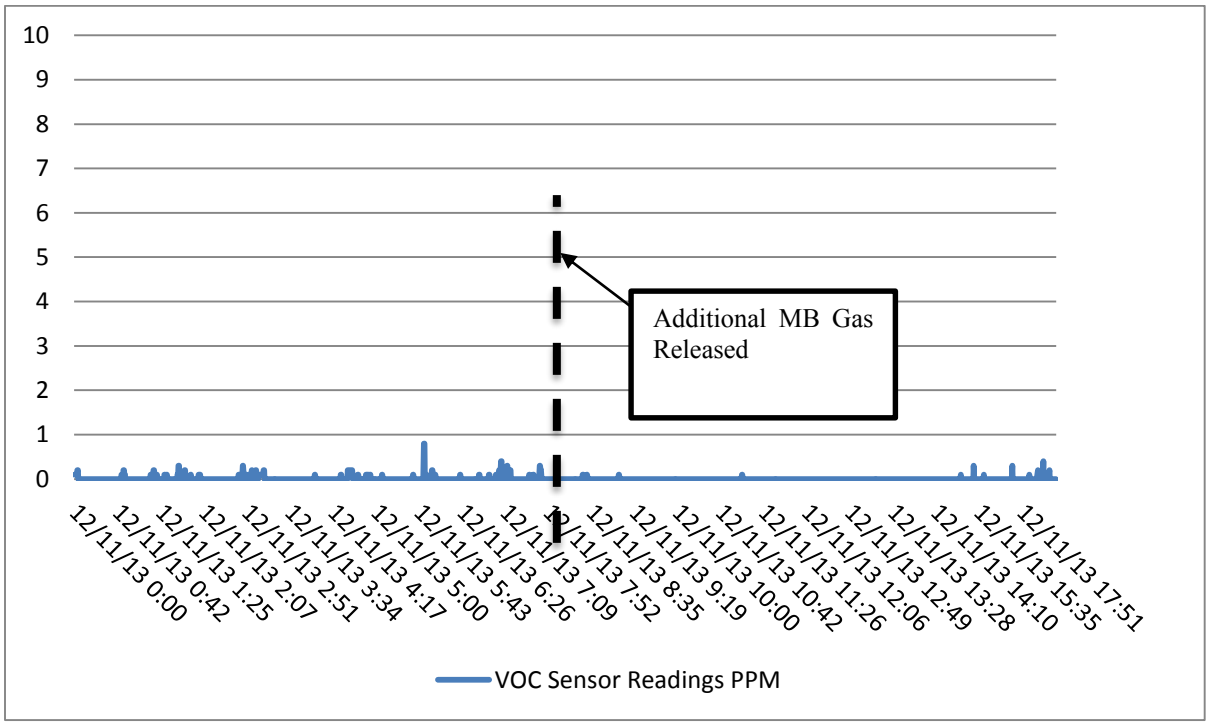

Figure B- 18. VOC Data from Location 106 LINC 42, 12/11/13

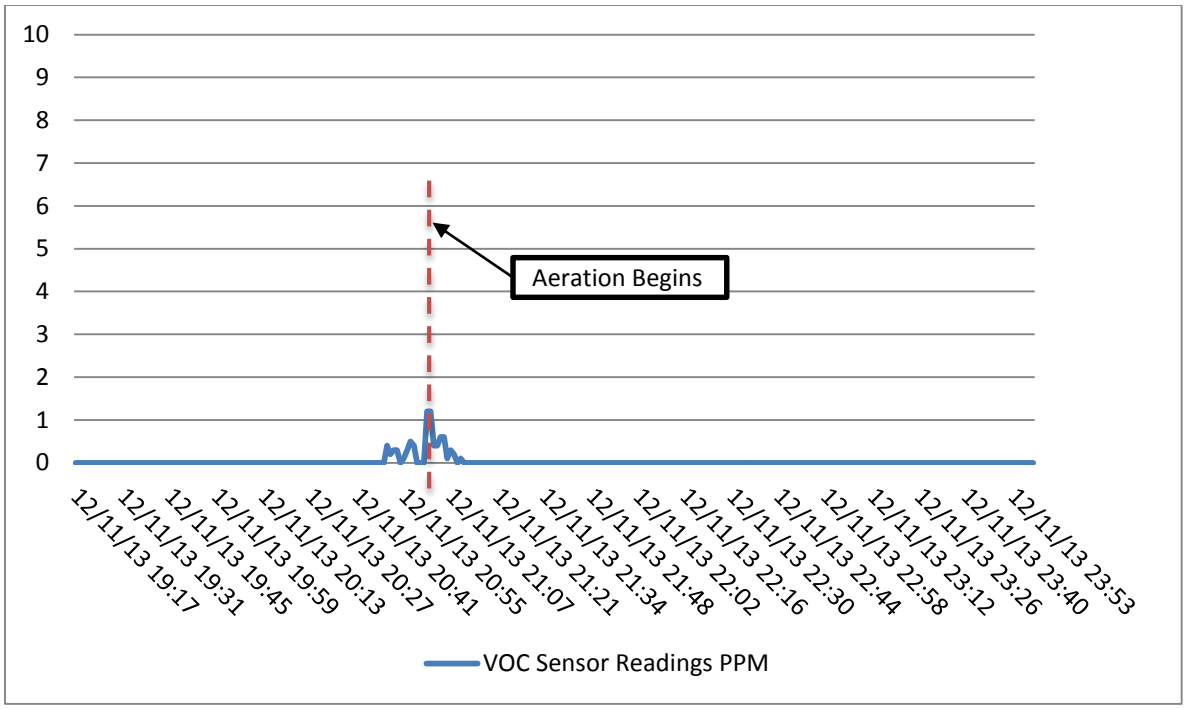

Figure B- 19. VOC Data from Location 201 LINC 78, 12/11/13

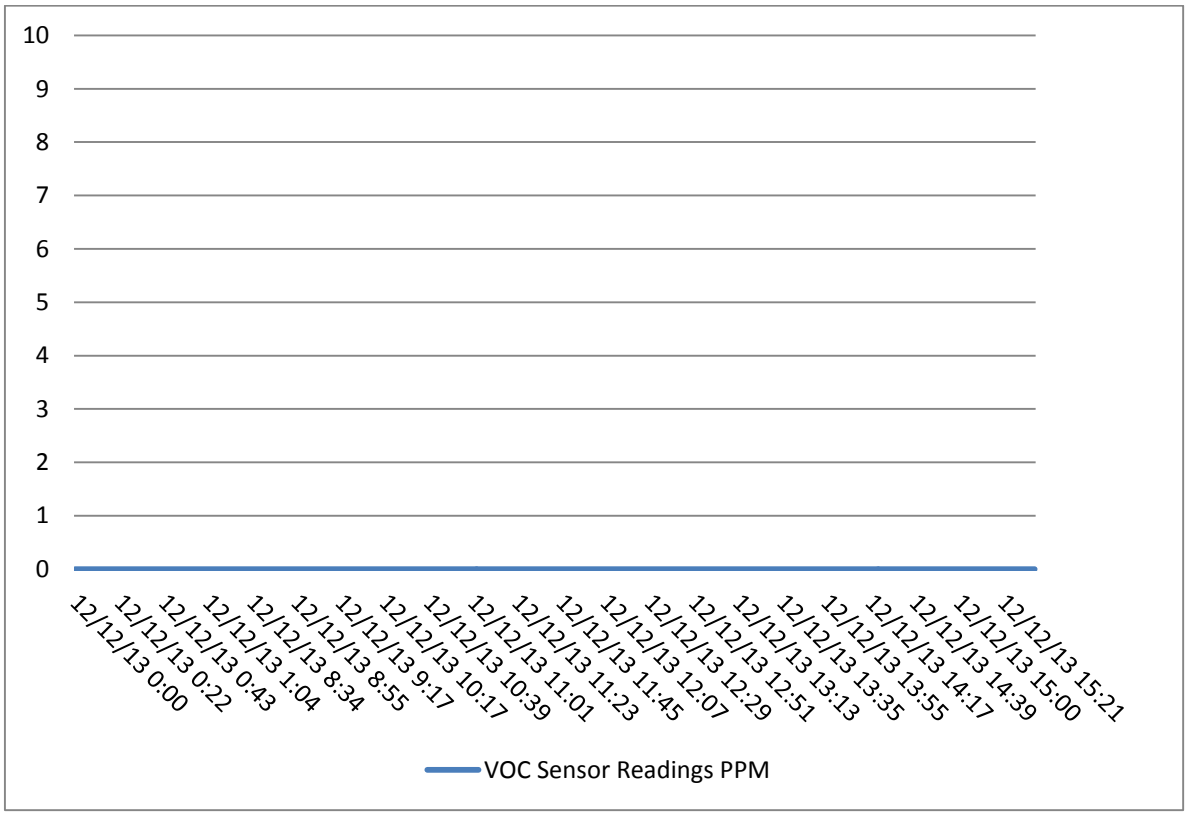

Figure B- 20. VOC Data from Location 201 LINC 78, 12/12/13

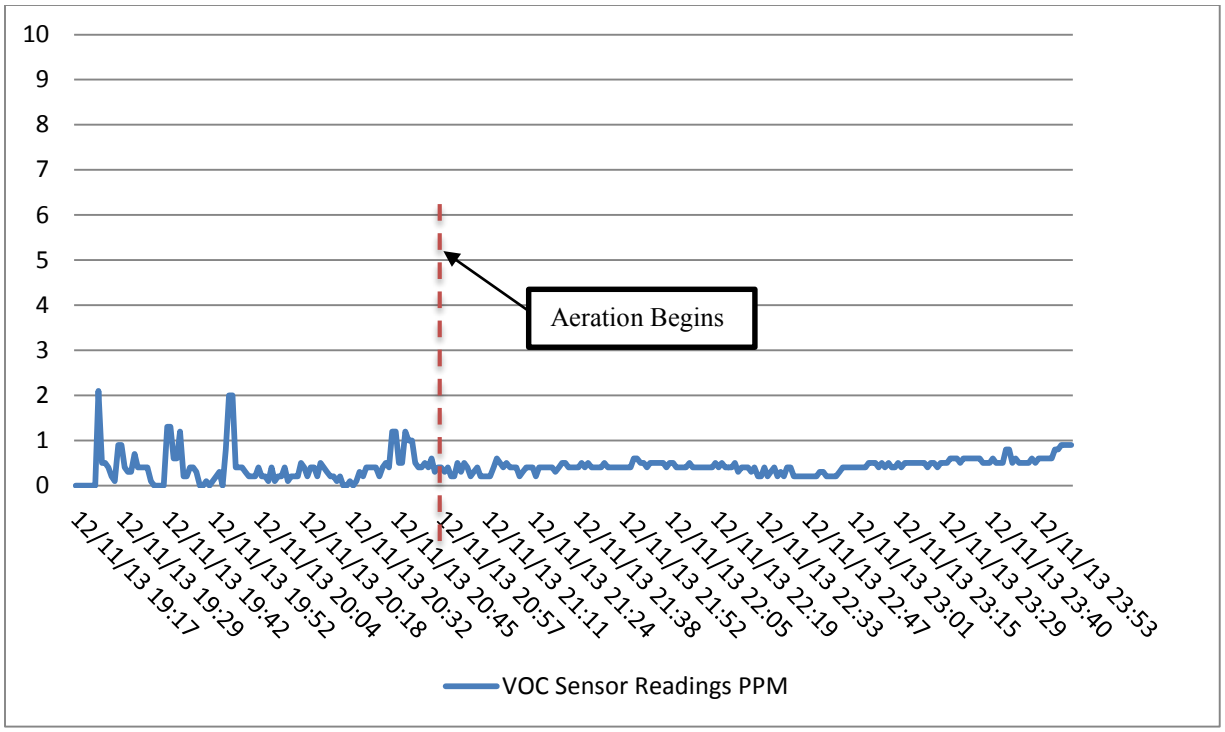

Figure B- 21. VOC Data from Location 202 LINC 109, 12/11/13

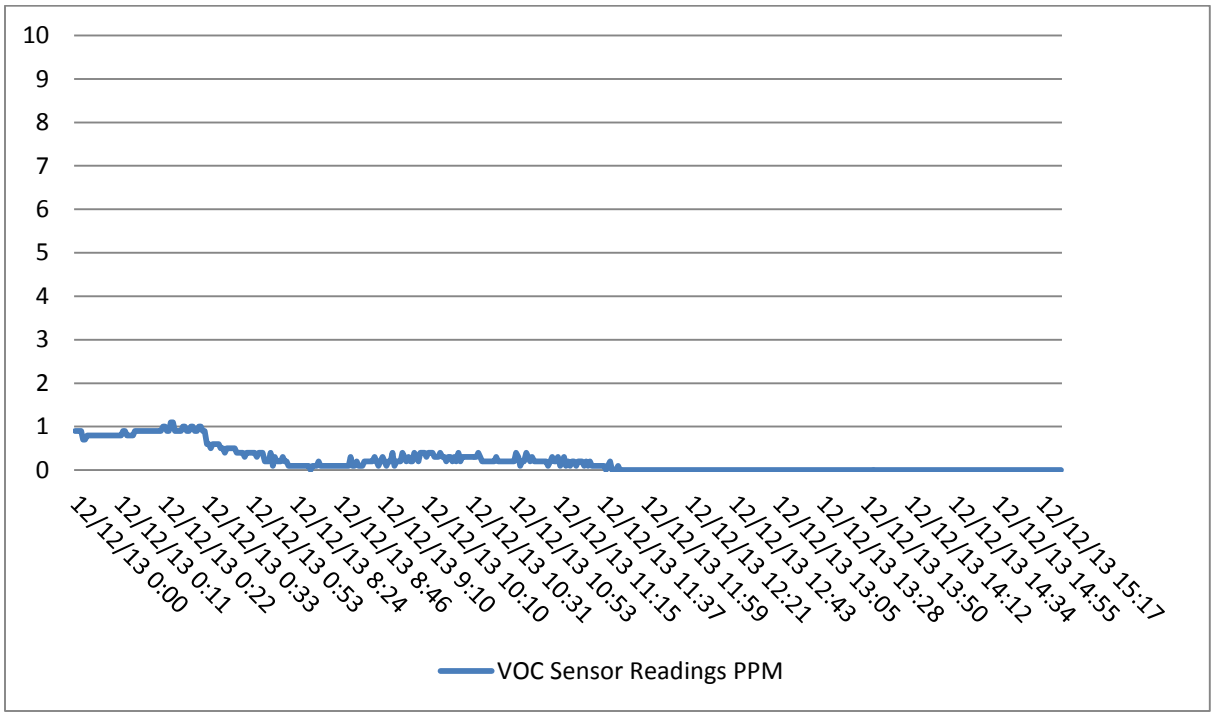

Figure B- 22. VOC Data from Location 202 LINC 109, 12/12/13

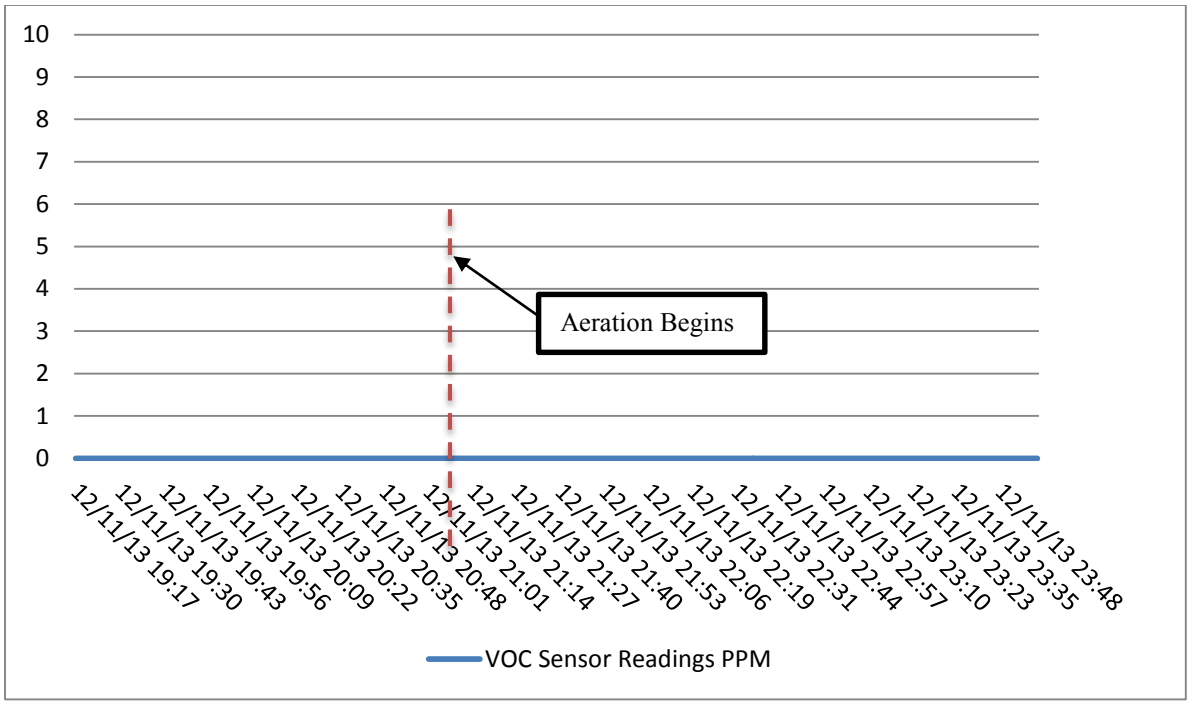

Figure B- 23. VOC Data from Location 203 LINC 33, 12/11/13

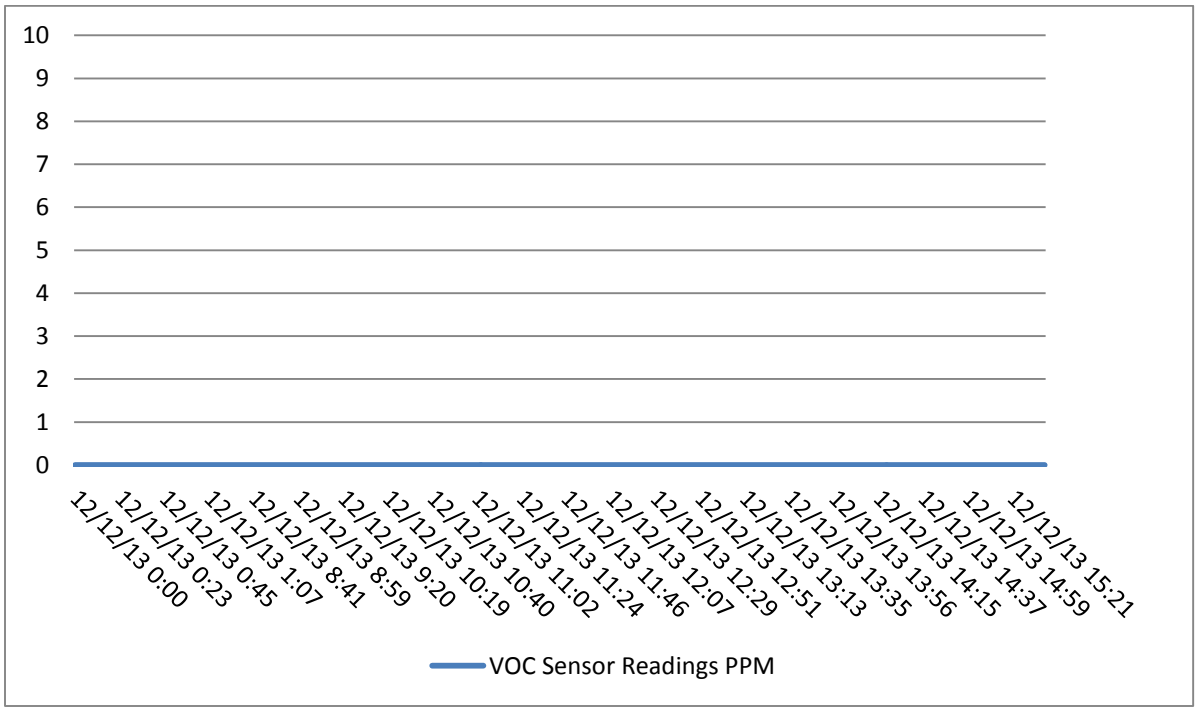

Figure B- 24. VOC Data from Location 203 LINC 33, 12/12/13

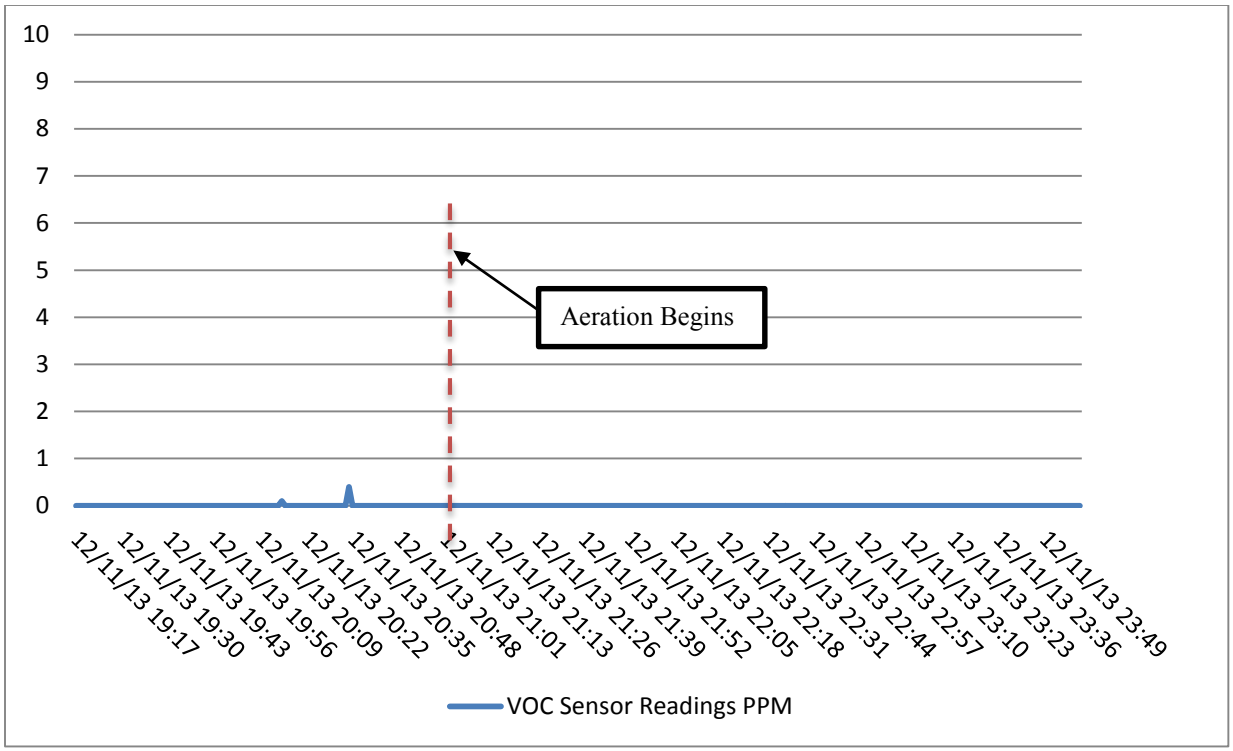

Figure B- 25. VOC Data from Location 204 LINC 80, 12/11/13

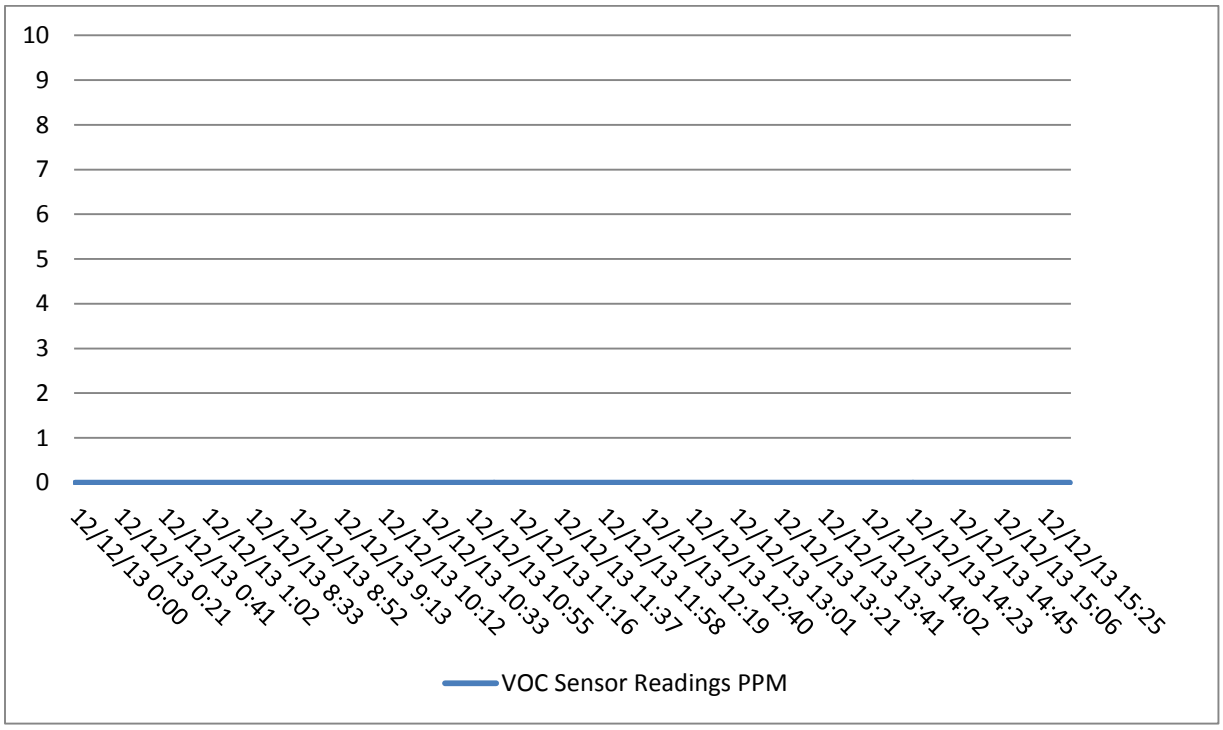

Figure B- 26. VOC Data from Location 204 LINC 80, 12/12/13

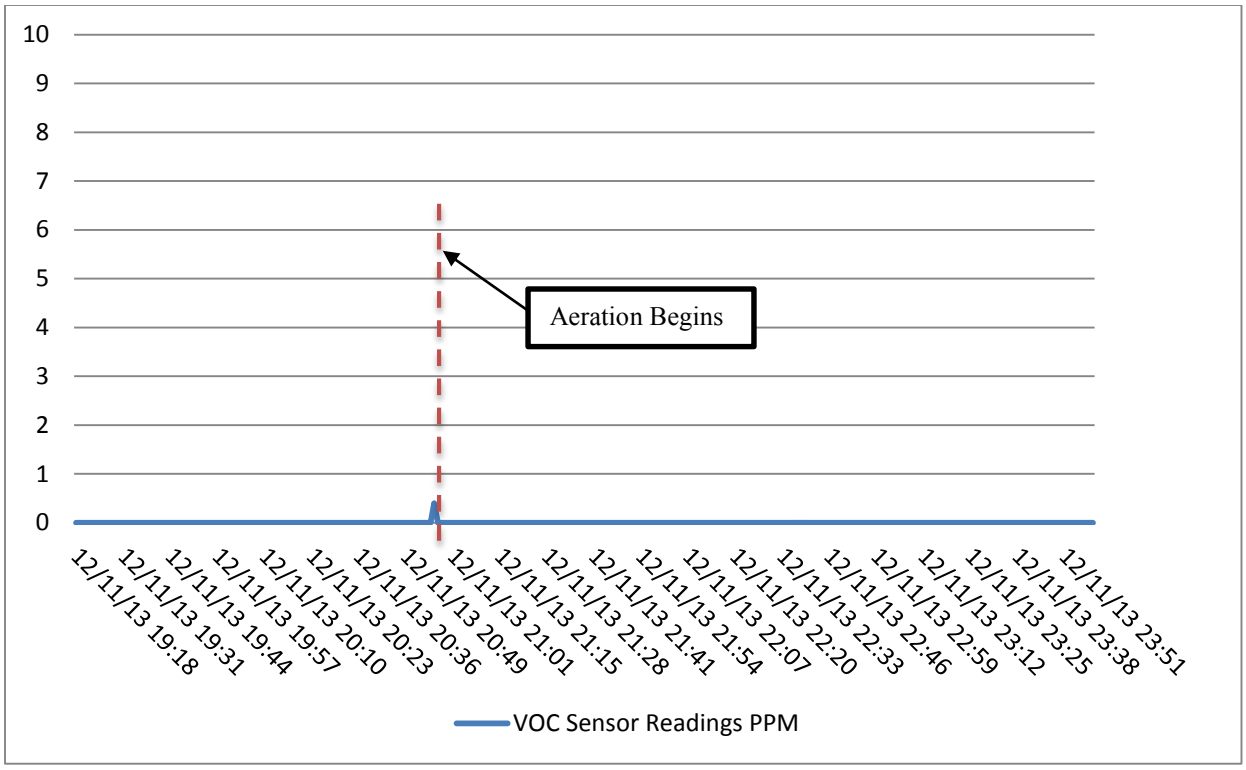

Figure B- 27. VOC Data from Location 205 LINC 76, 12/11/13

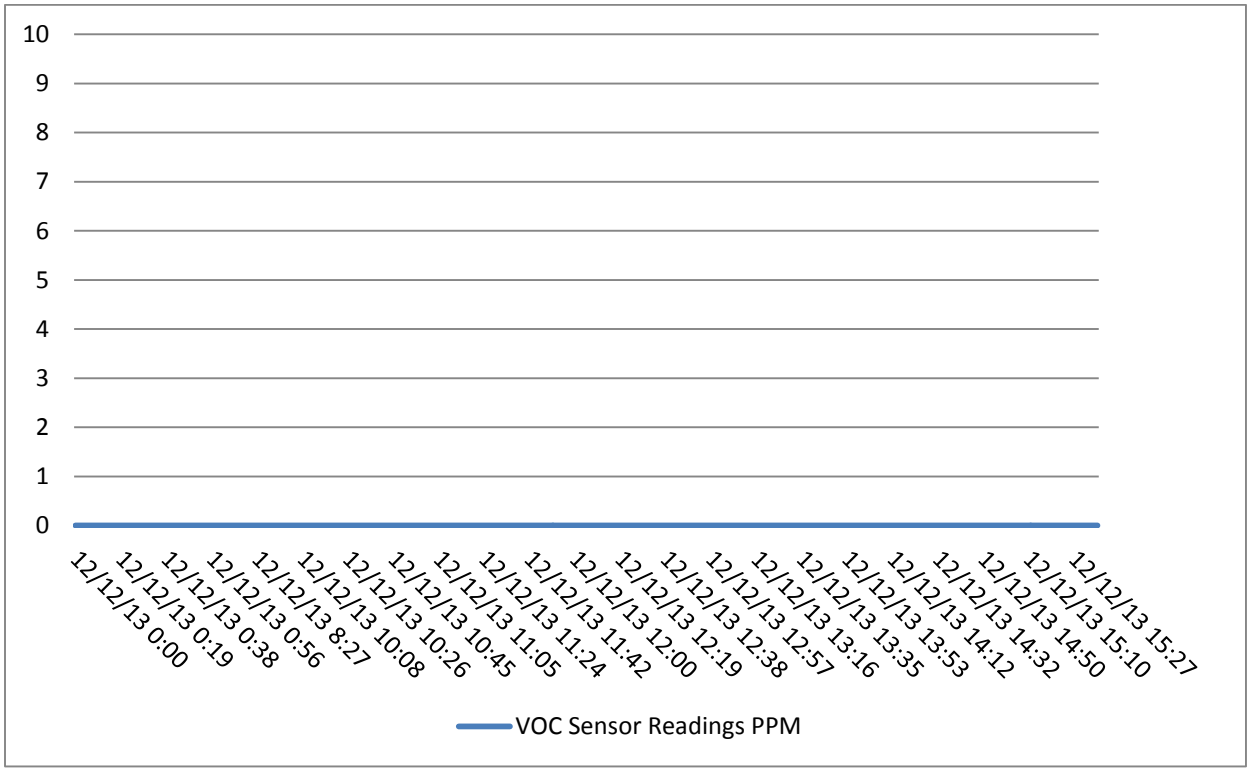

Figure B- 28. VOC Data from Location 205 LINC 76, 12/12/13

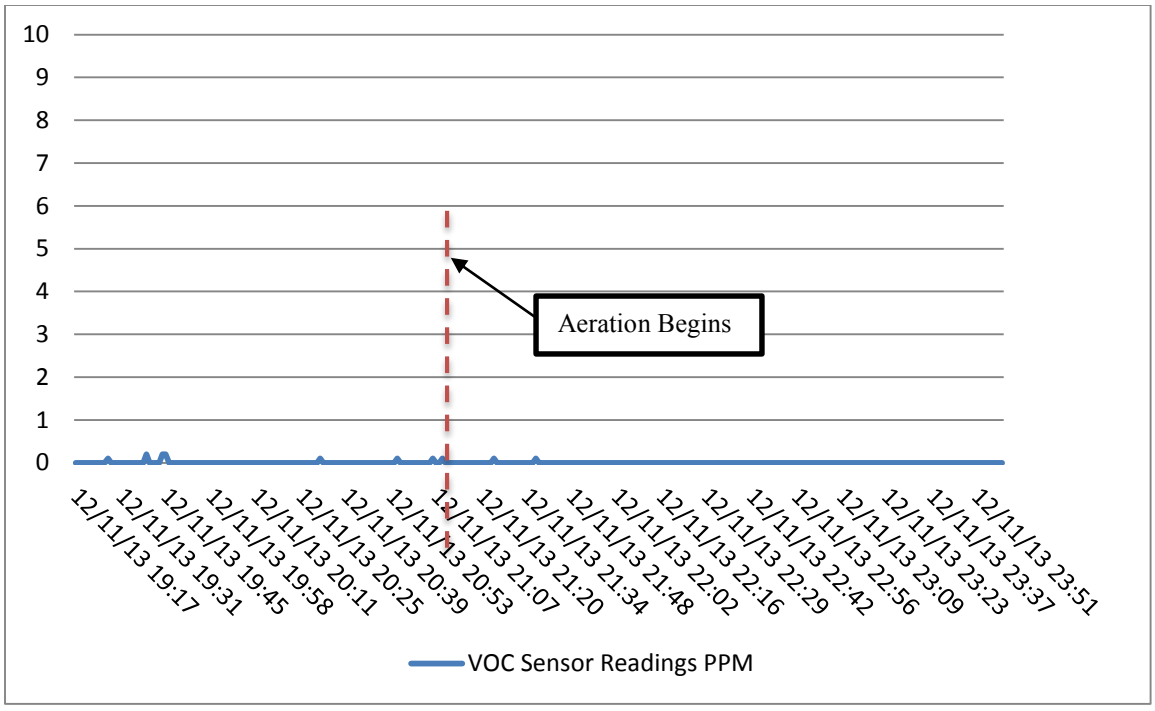

Figure B- 29. VOC Data from Location 206 LINC 42, 12/11/13

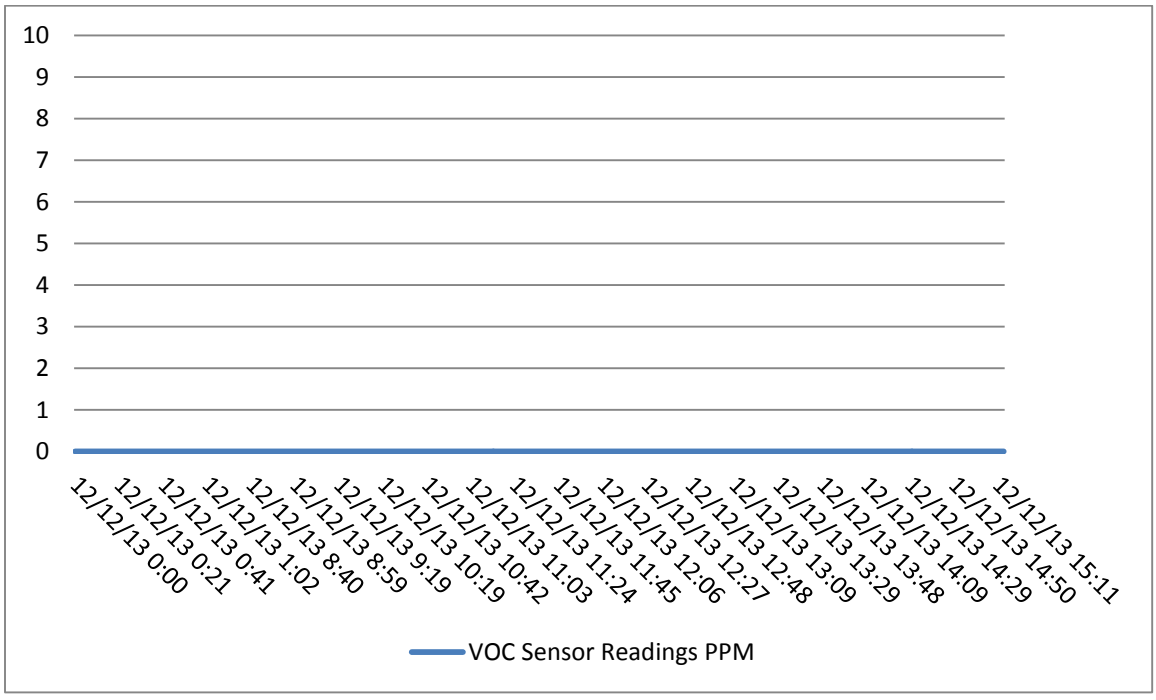

Figure B- 30. VOC Data from Location 206 LINC 42, 12/12/13

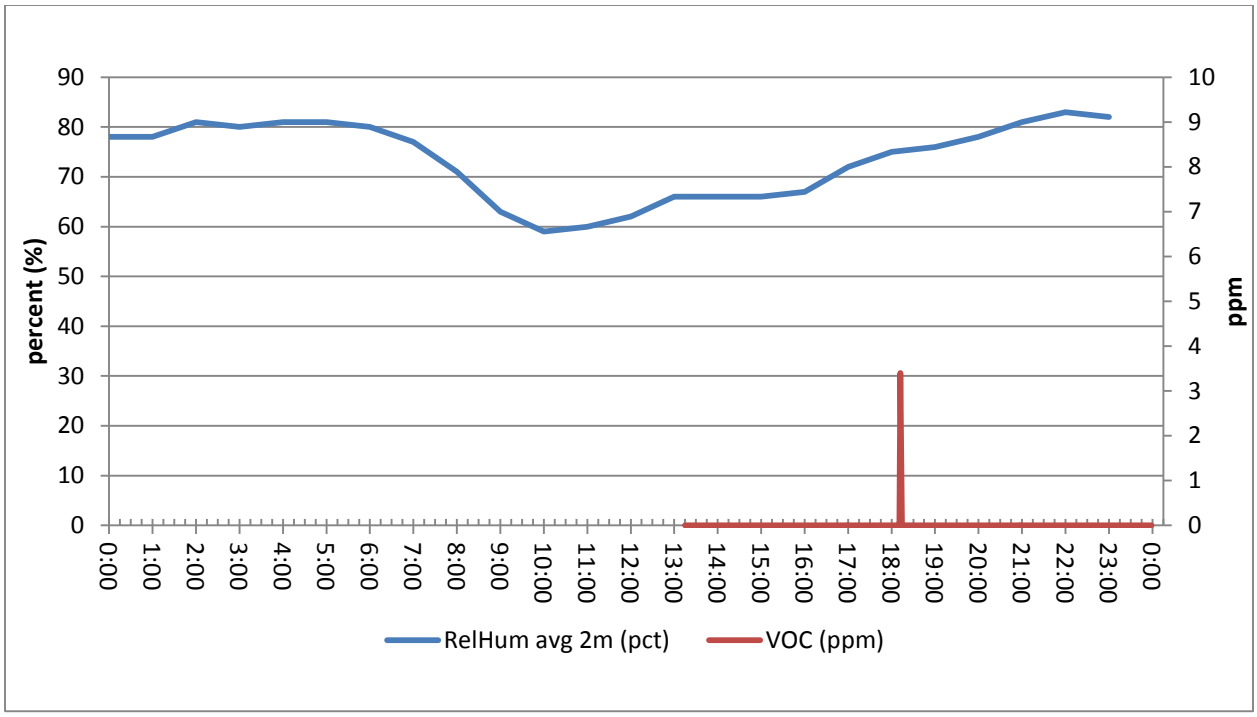

Figure B- 31. VOC Levels & Ambient Relative Humidity, Location 101 & 201 LINC 78, 12/09/2013.

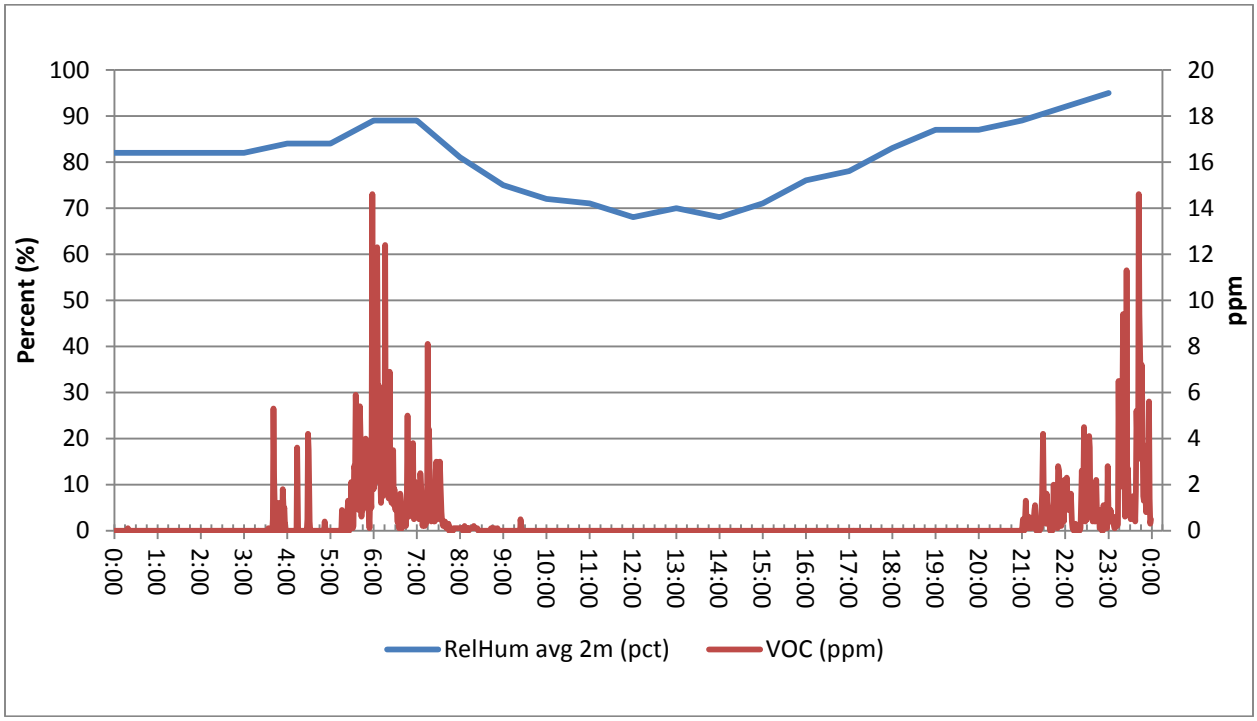

Figure B- 32. VOC Levels & Ambient Relative Humidity, Location 101 & 201 LINC 78, 12/10/2013.

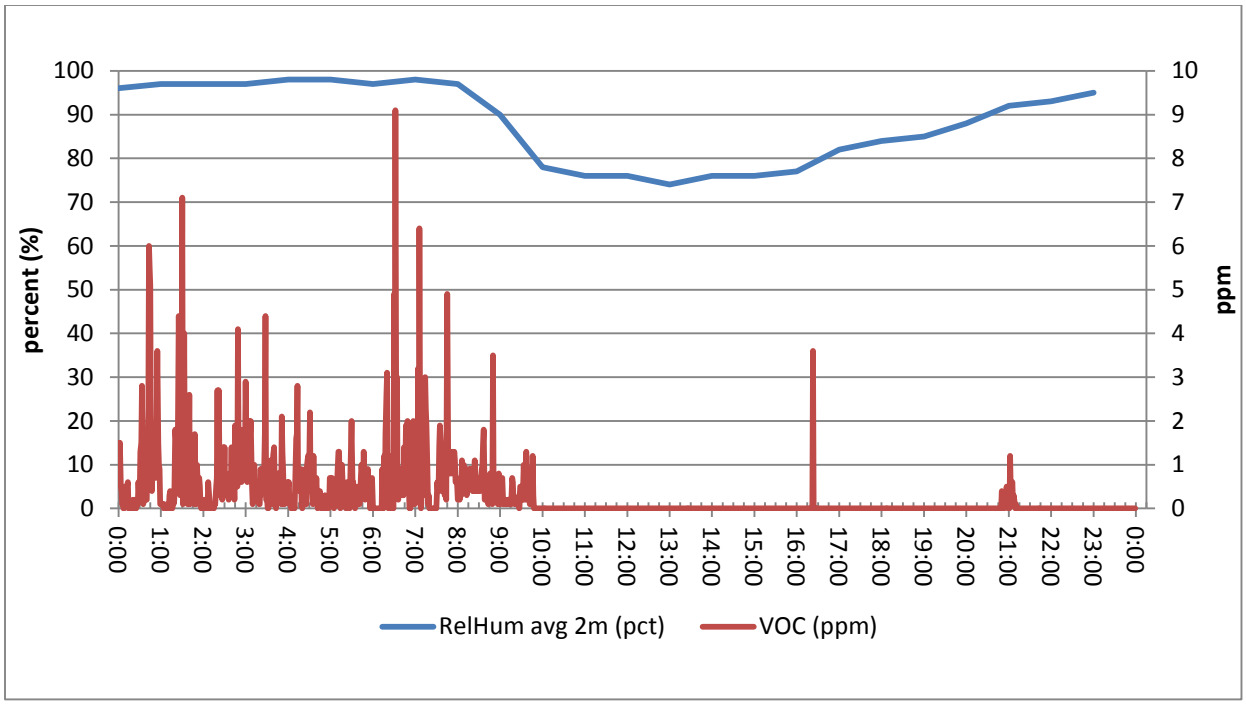

Figure B- 33. VOC Levels & Ambient Relative Humidity, Location 101 & 201 LINC 78, 12/11/2013

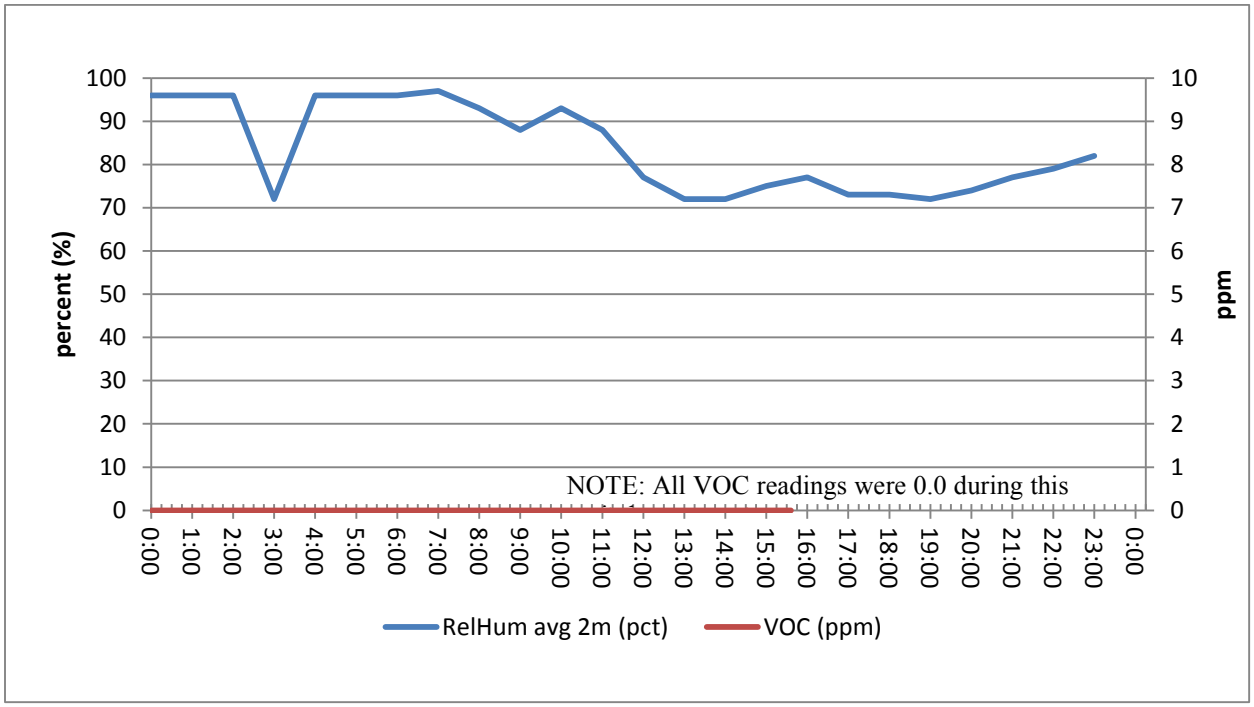

Figure B- 34. VOC Levels & Ambient Relative Humidity, Location 101 & 201 LINC 78, 12/12/2013

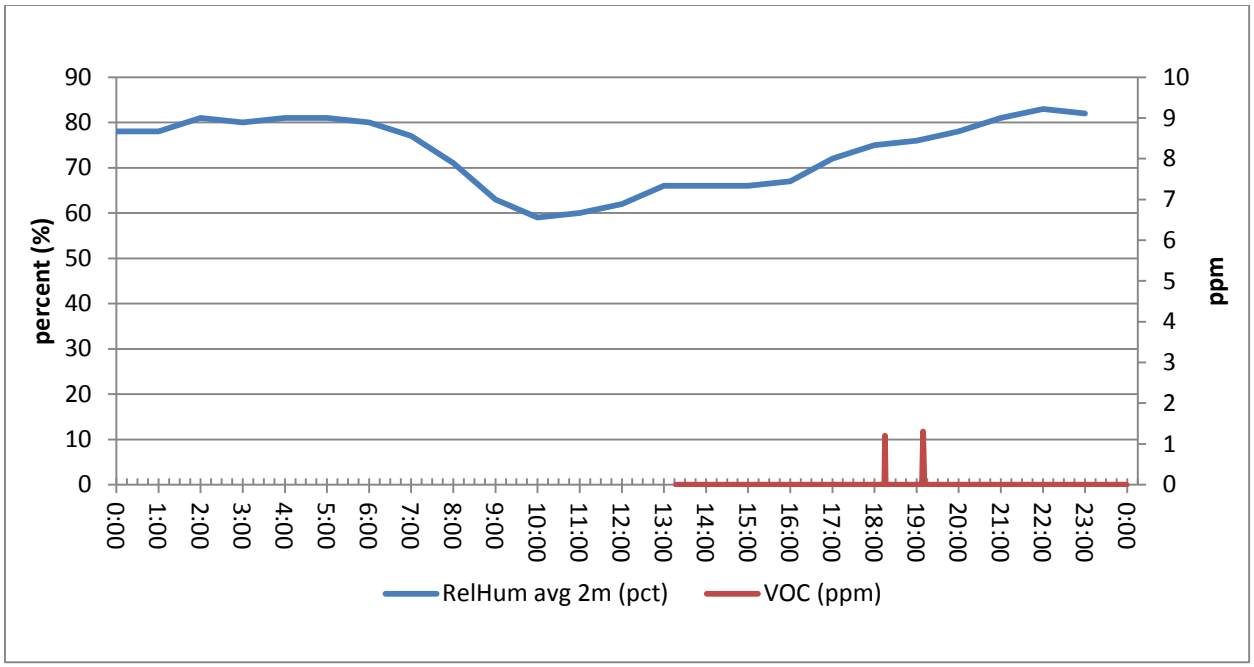

Figure B- 35. VOC Levels & Ambient Outdoor Relative Humidity, Location 102 & 202 LINC 109, 12/09/2013

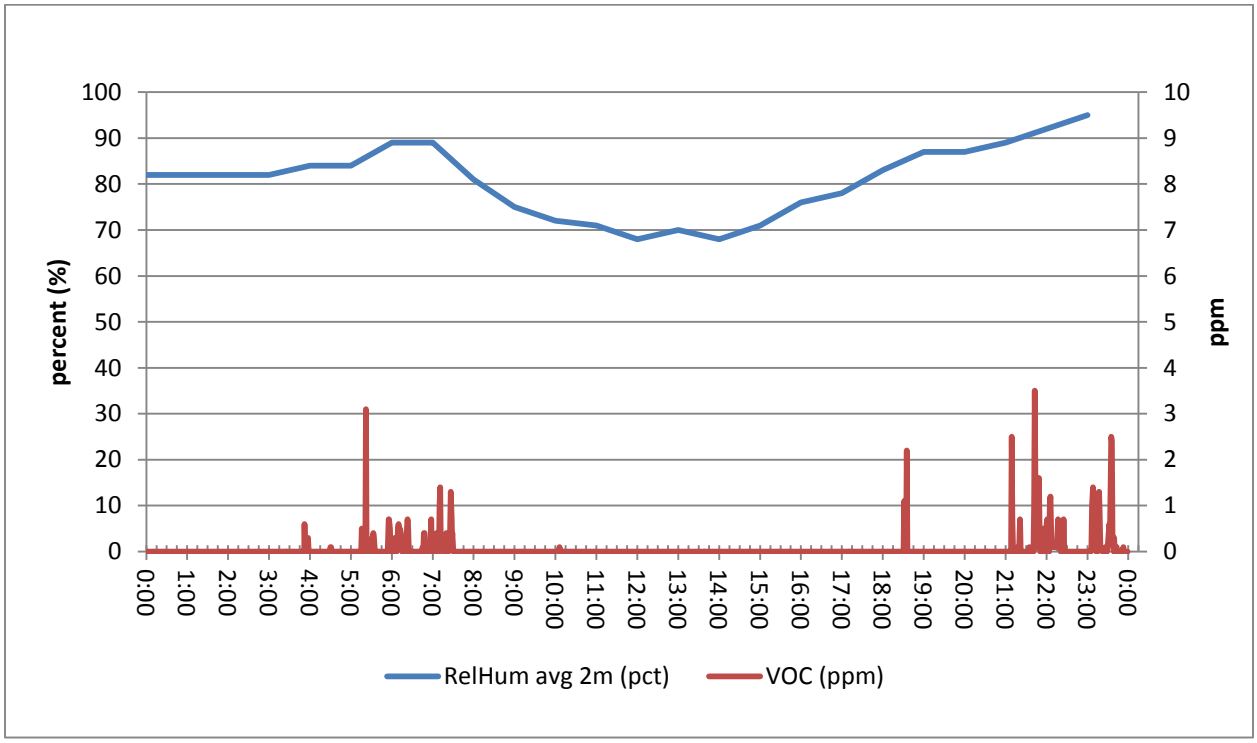

Figure B- 36. VOC Levels & Ambient Relative Humidity, Location 102 & 202 LINC 109, 12/10/2013

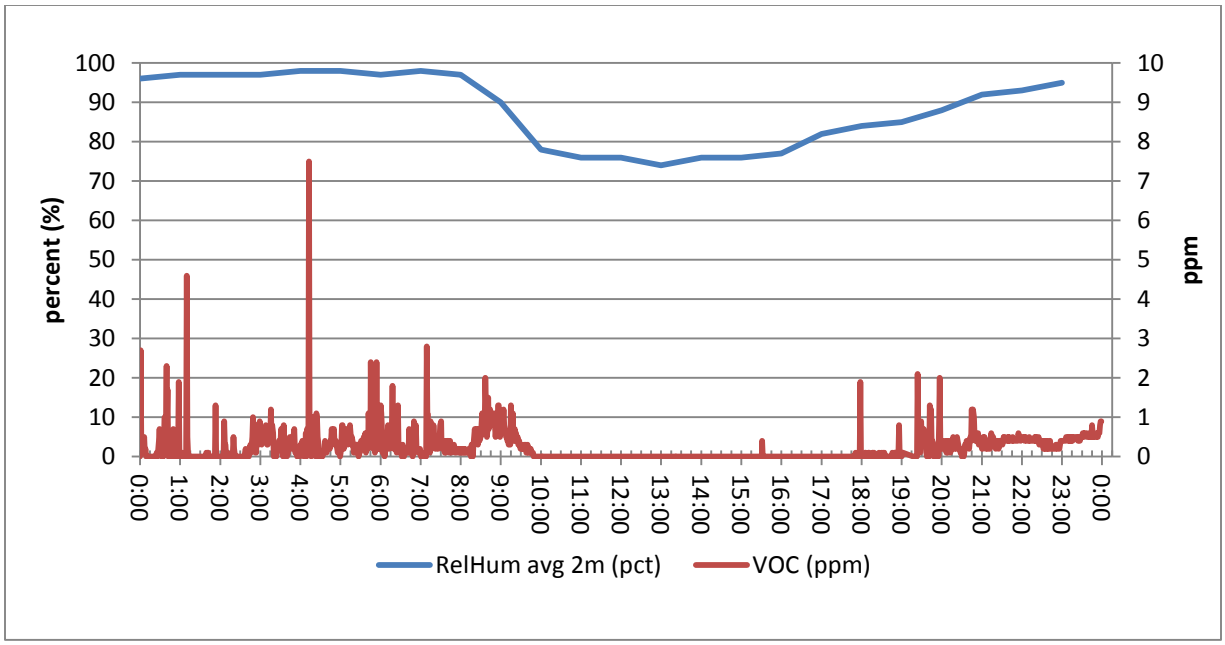

Figure B- 37. VOC Levels & Ambient Relative Humidity, Location 102 & 202 LINC 109, 12/11/2013

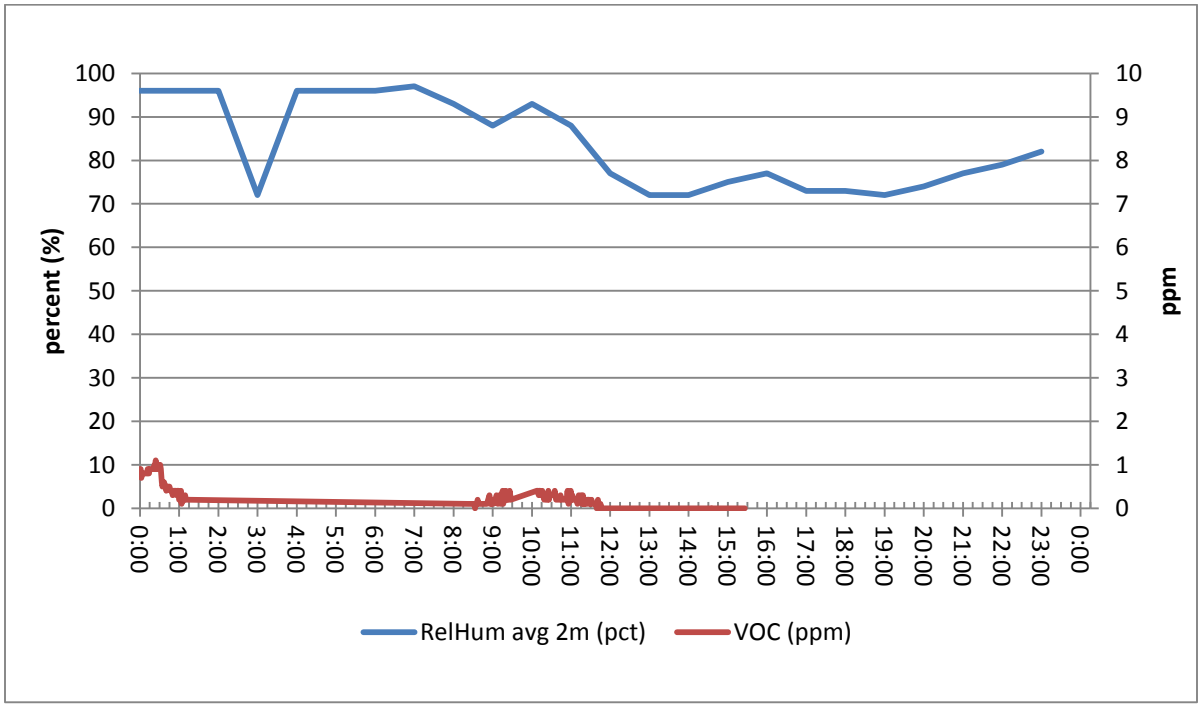

Figure B- 38. VOC Levels & Ambient Relative Humidity, Location 102 & 202 LINC 109, 12/12/2013

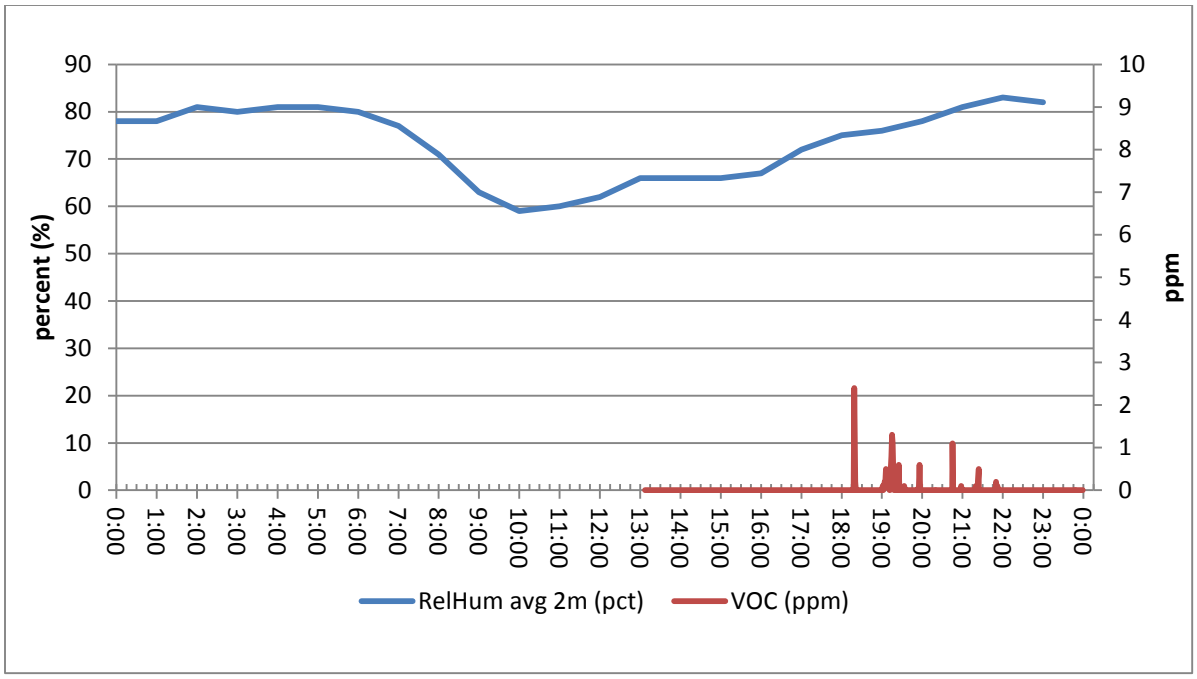

Figure B- 39. VOC Levels & Ambient Relative Humidity, Location 103-205 LINC 76, 12/09/2013

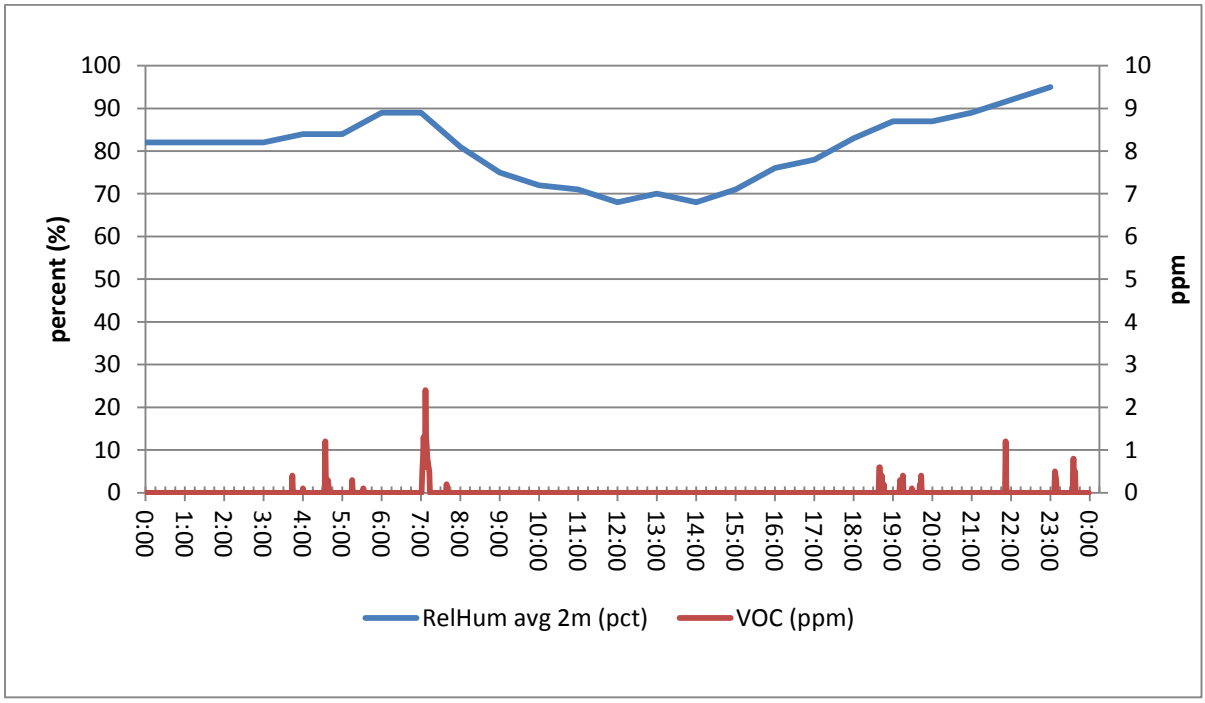

Figure B- 40. VOC Levels & Ambient Relative Humidity, Location 103-205 LINC 76, 12/10/2013

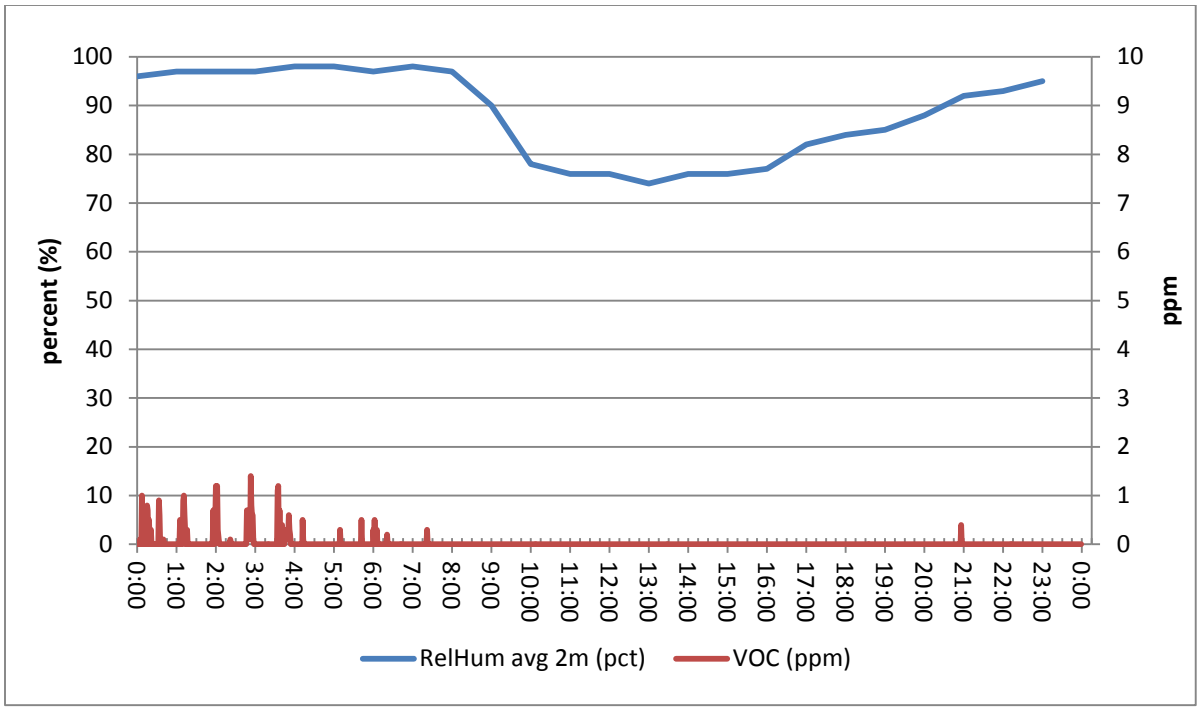

Figure B- 41. VOC Levels & Ambient Relative Humidity, Location 103-205 LINC 76, 12/11/2013

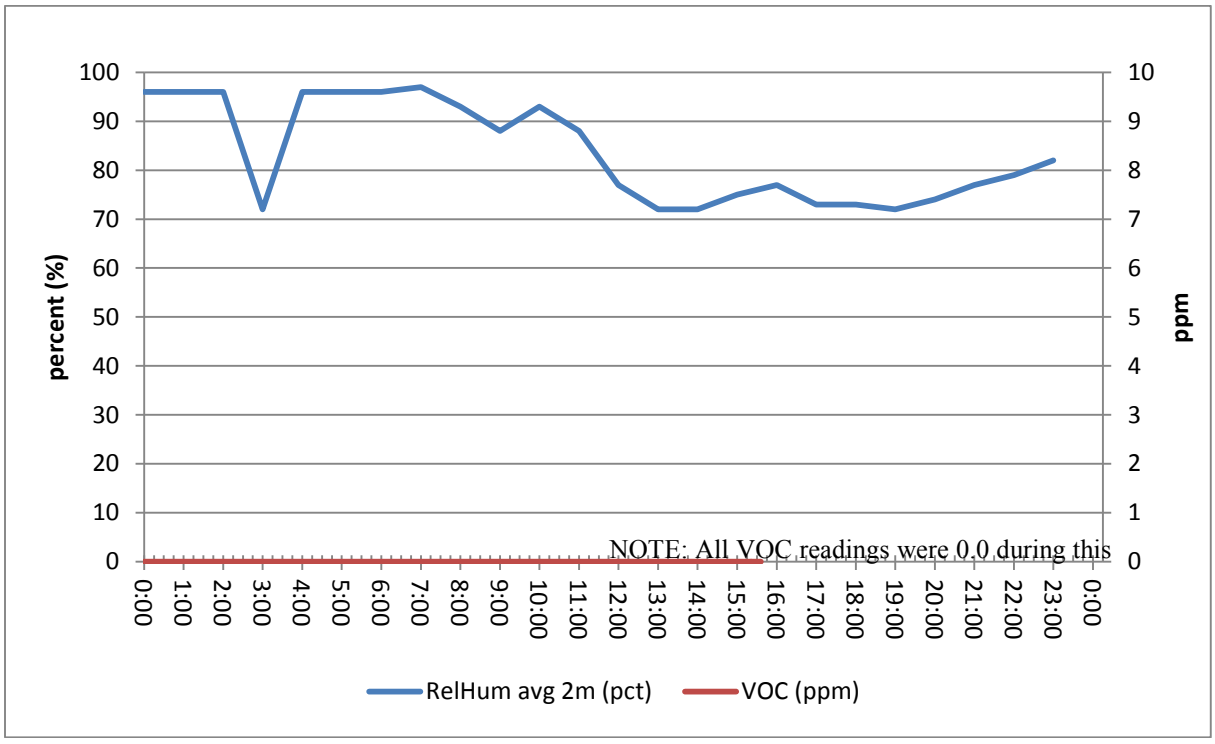

Figure B- 42. VOC Levels & Ambient Relative Humidity, Location 103-205 LINC 76, 12/12/2013

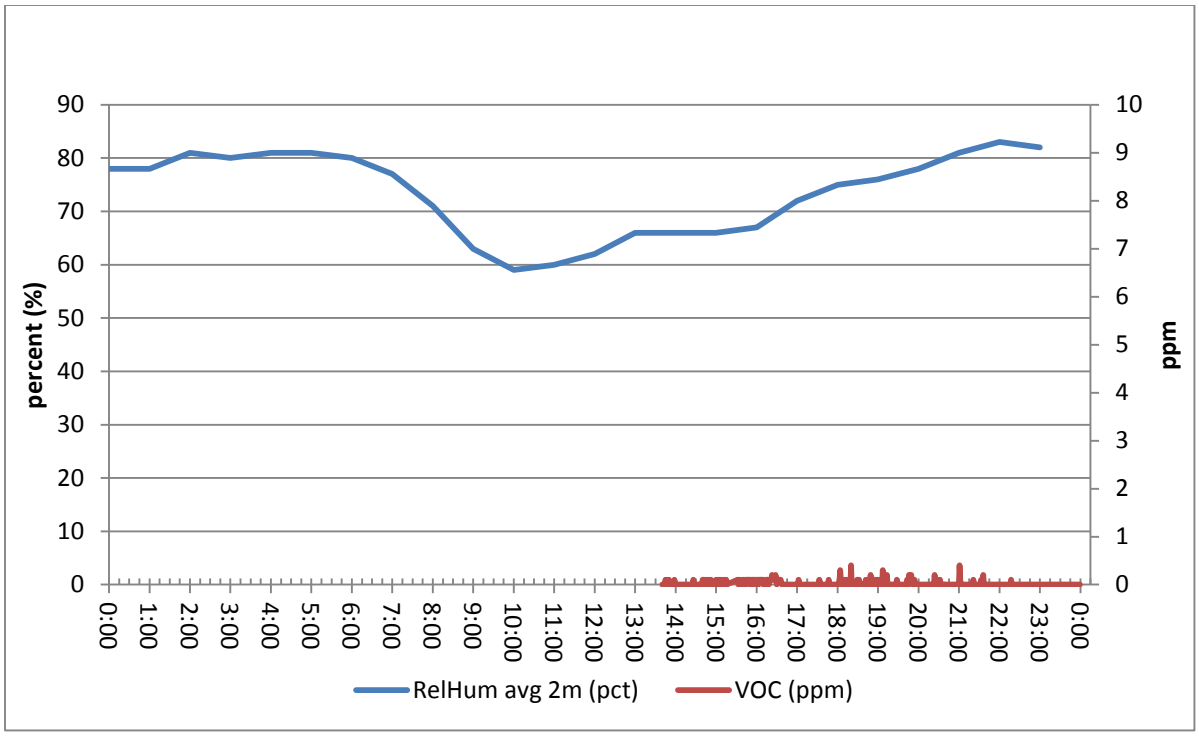

Figure B- 43. VOC Levels & Ambient Relative Humidity, Location 104-203 LINC 33, 12/09/2013

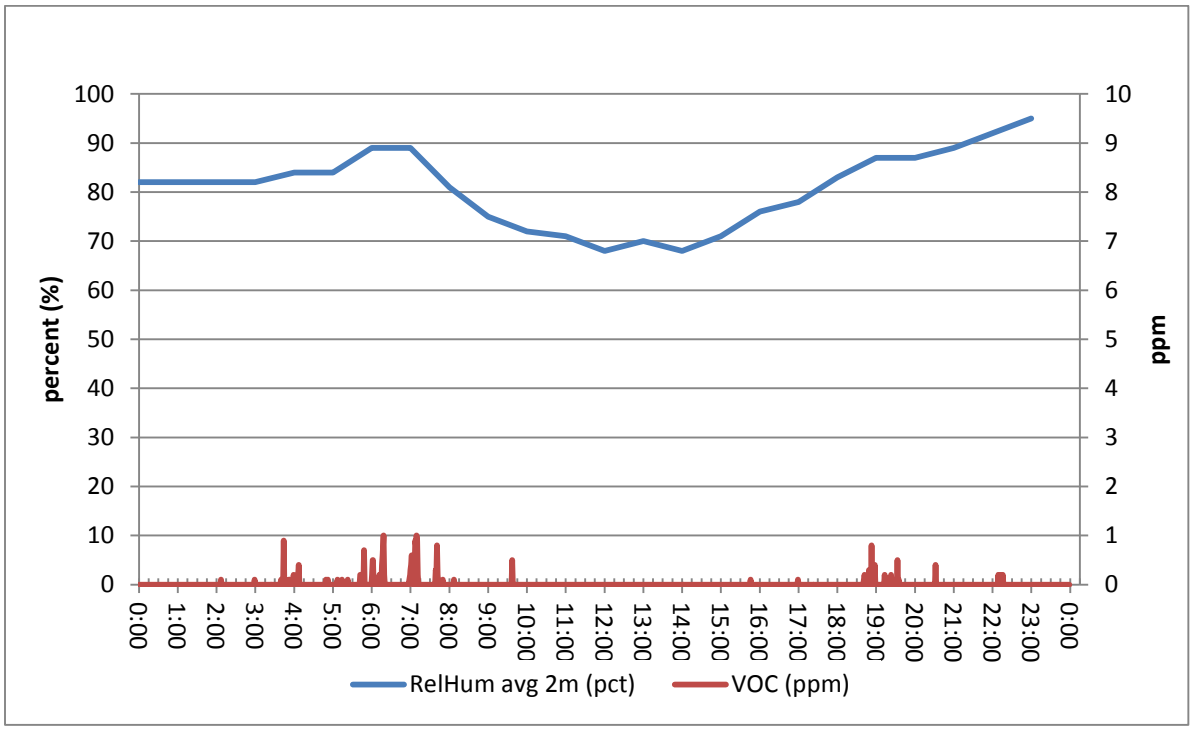

Figure B- 44. VOC Levels & Ambient Relative Humidity, Location 104-203 LINC 33, 12/10/2013

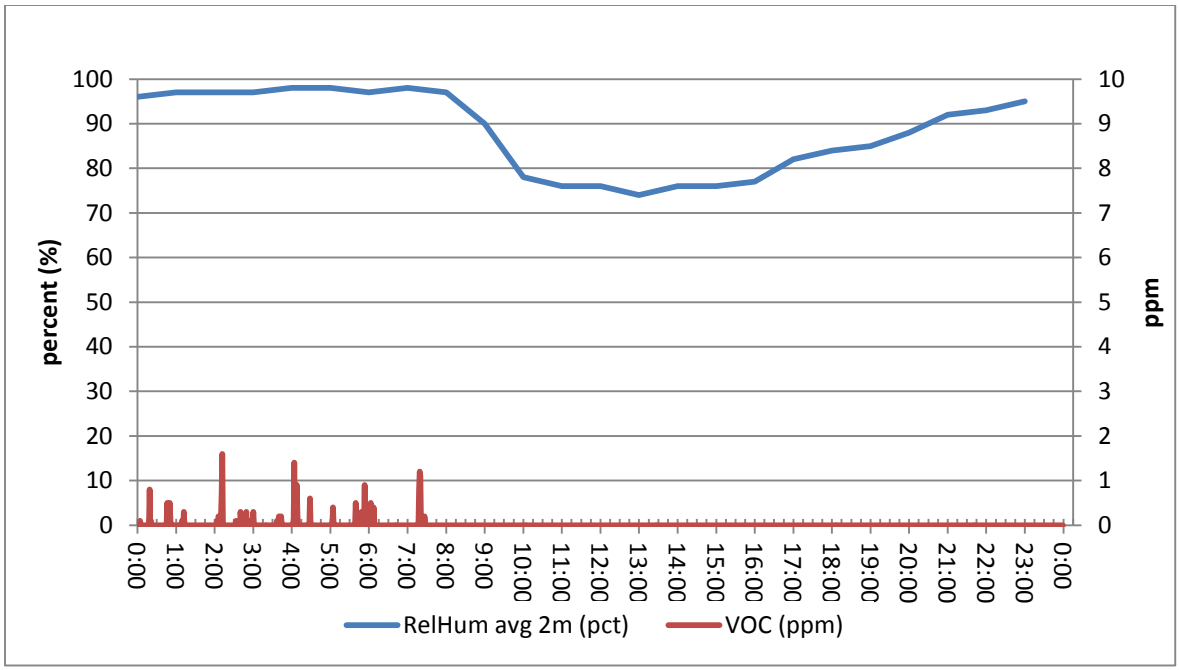

Figure B- 45. VOC Levels & Ambient Relative Humidity, Location 104-203 LINC 33, 12/11/2013

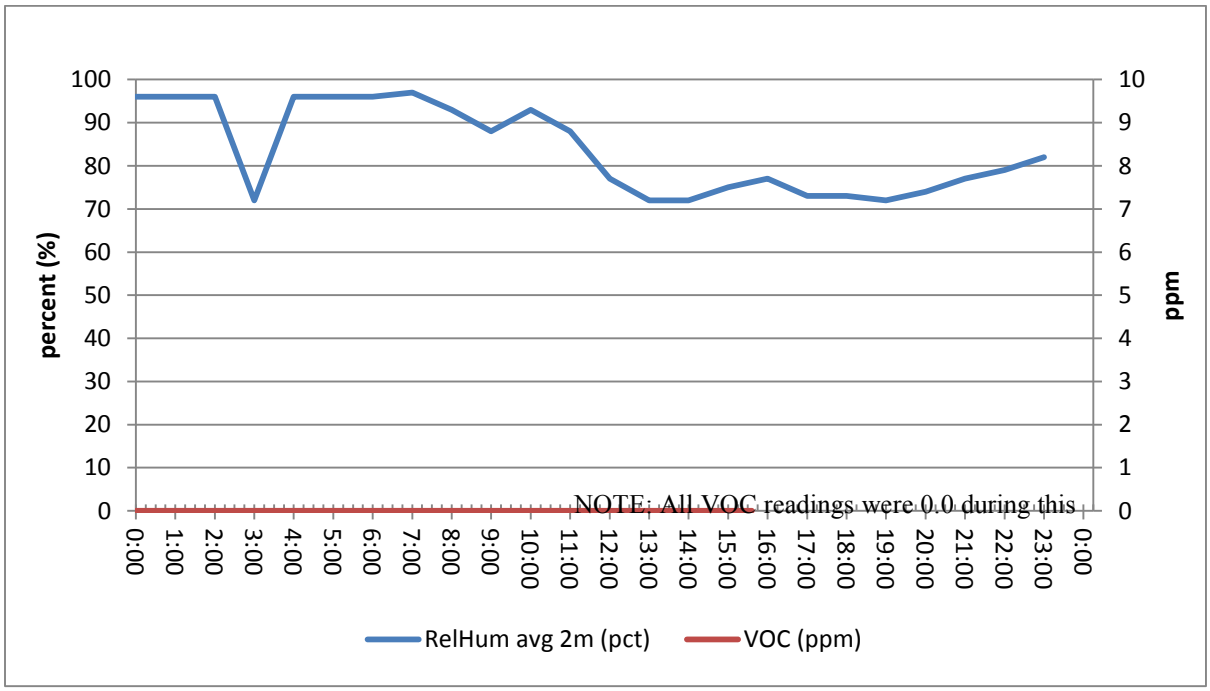

Figure B- 46. VOC Levels & Ambient Relative Humidity, Location 103-205 LINC 76, 12/12/2013

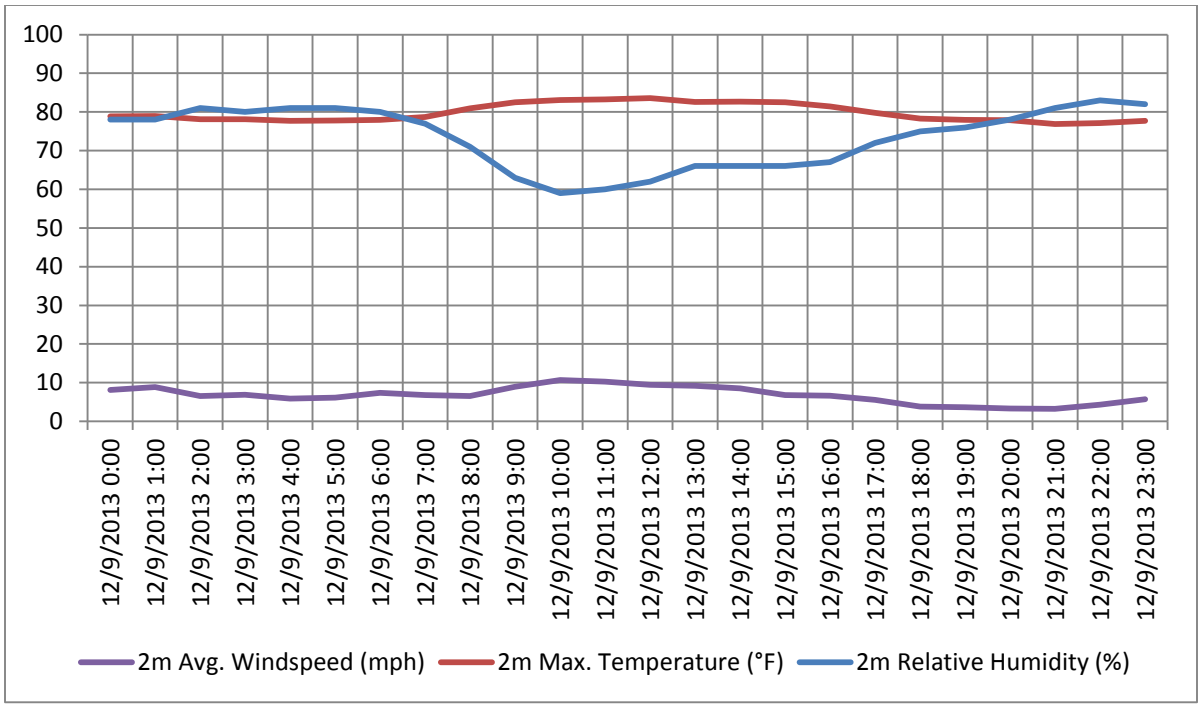

Figure B- 47. Ambient Temperature, Relative Humidity, and Windspeed, 12/09/13

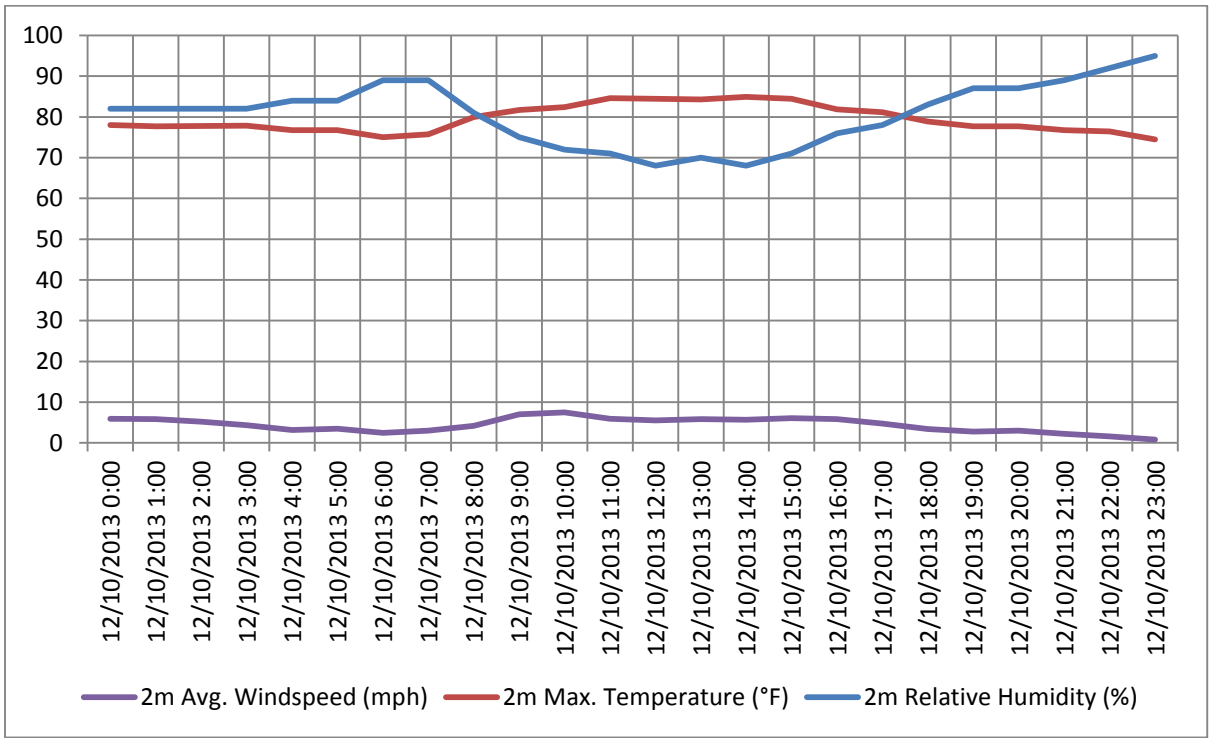

Figure B- 48. Ambient Temperature, Relative Humidity, and Windspeed, 12/10/13

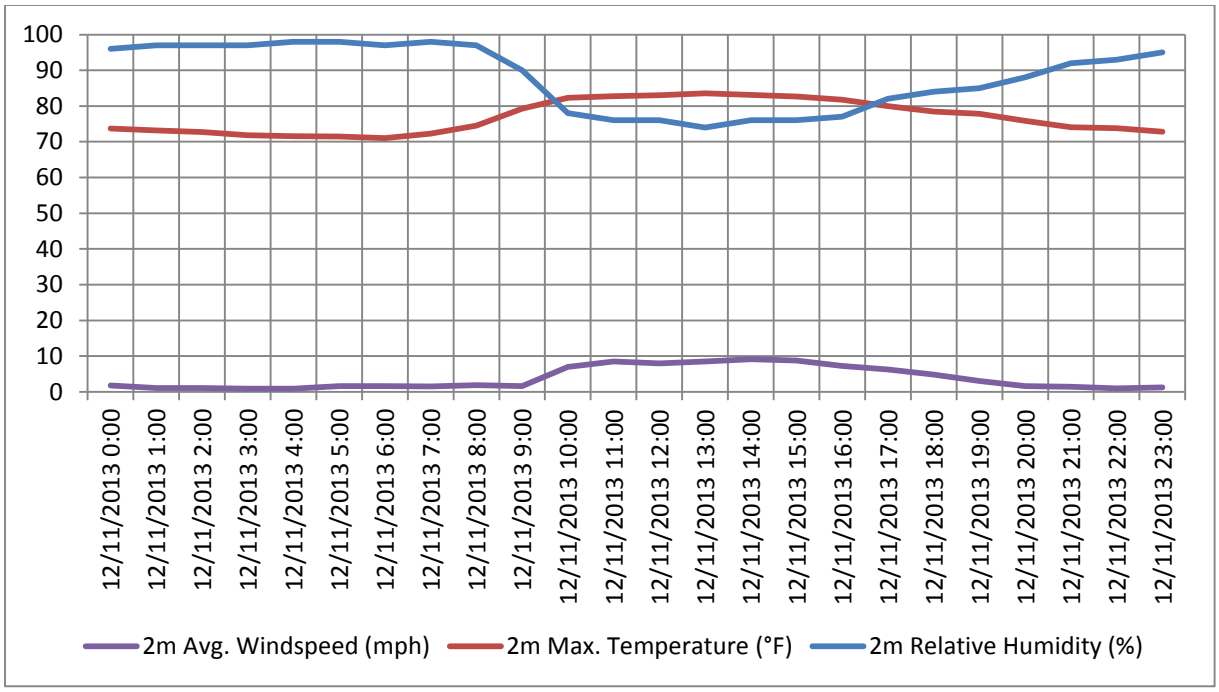

Figure B- 49. Ambient Temperature, Relative Humidity, and Windspeed, 12/11/13

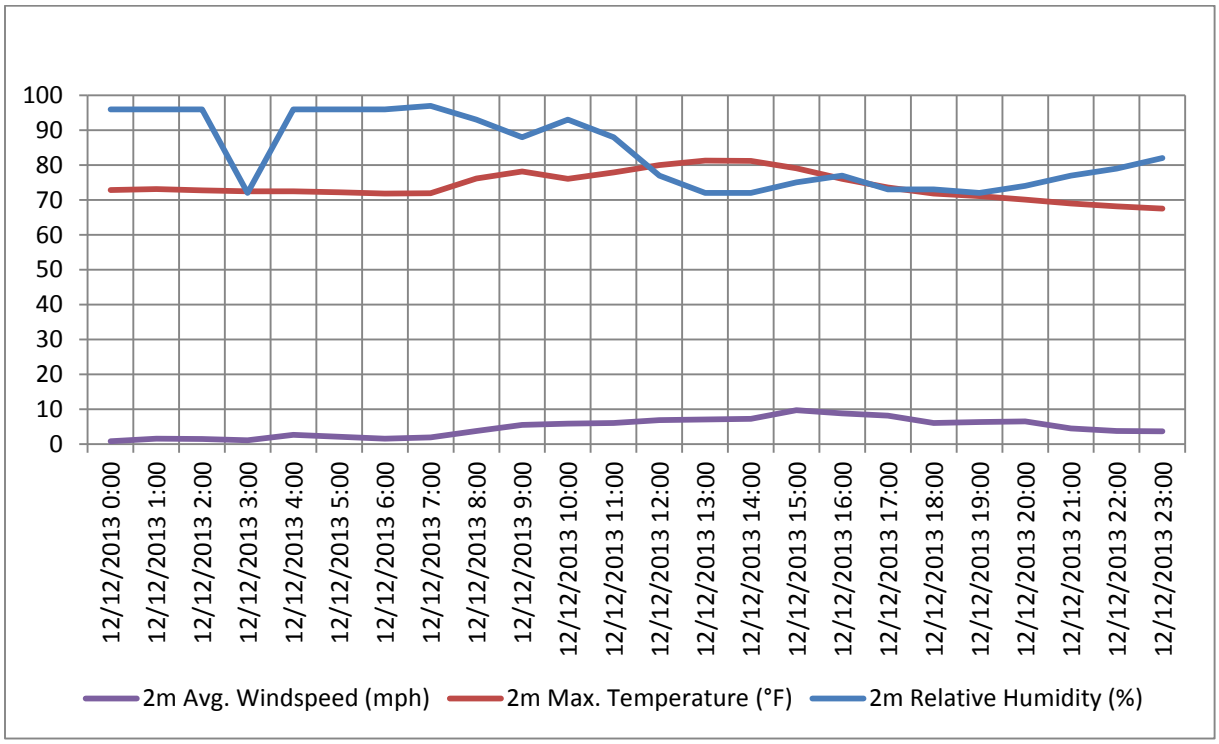

Figure B- 50. Ambient Temperature, Relative Humidity, and Windspeed, 12/12/13

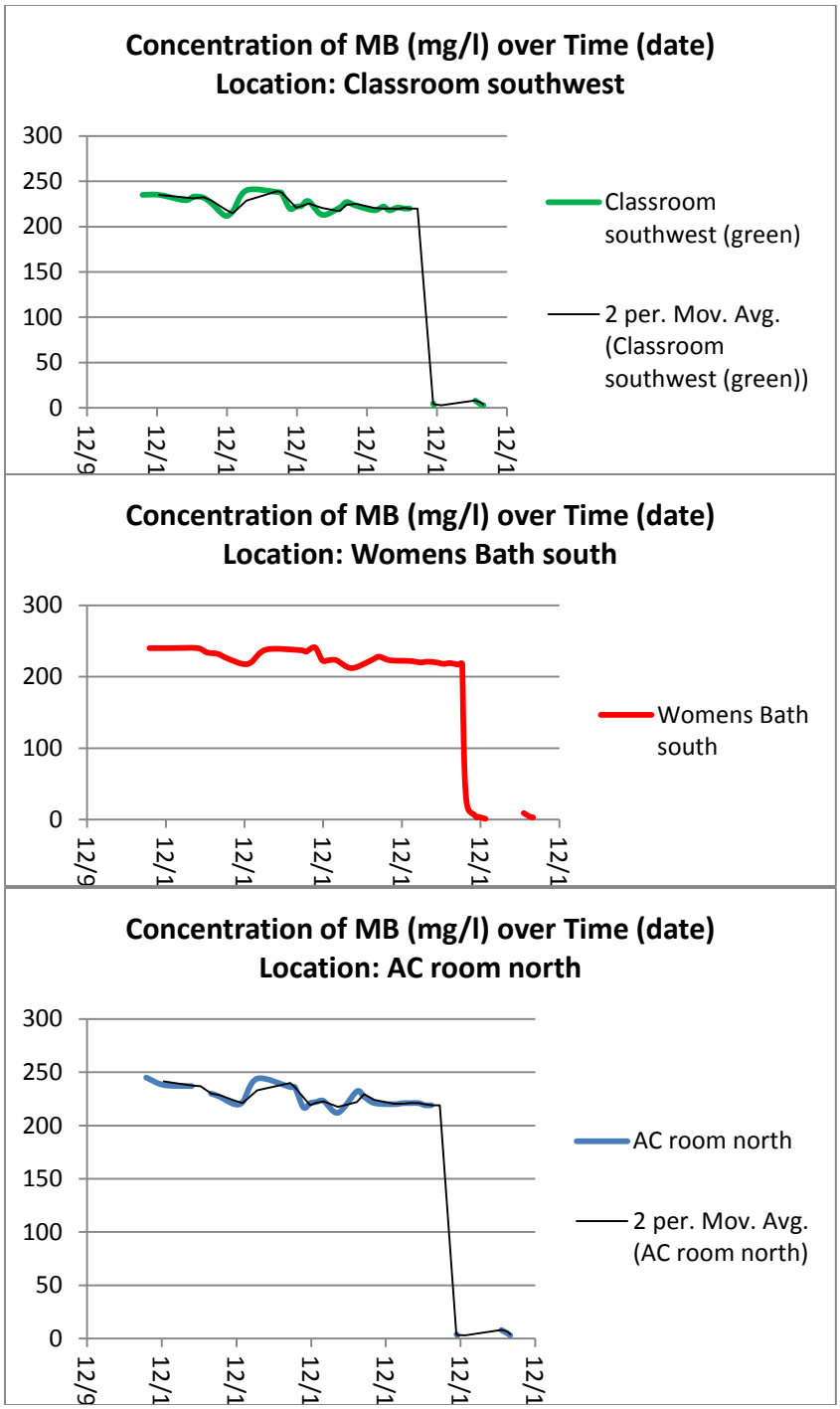

Figure B- 51. Concentration of MB (mg/l) over Time (date), Three Manually Monitored Locations

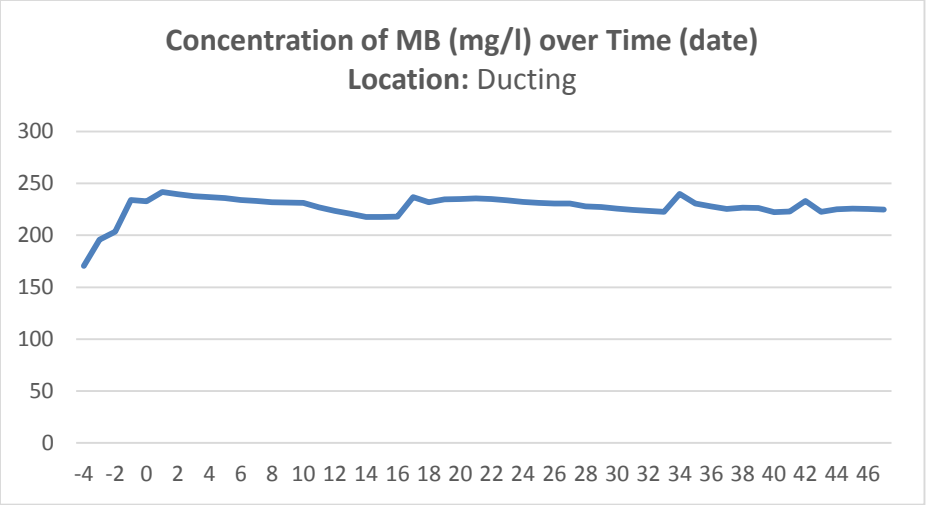

Figure B- 52. Concentration of MB in mg/l over Time (hr), Return Ducting Location

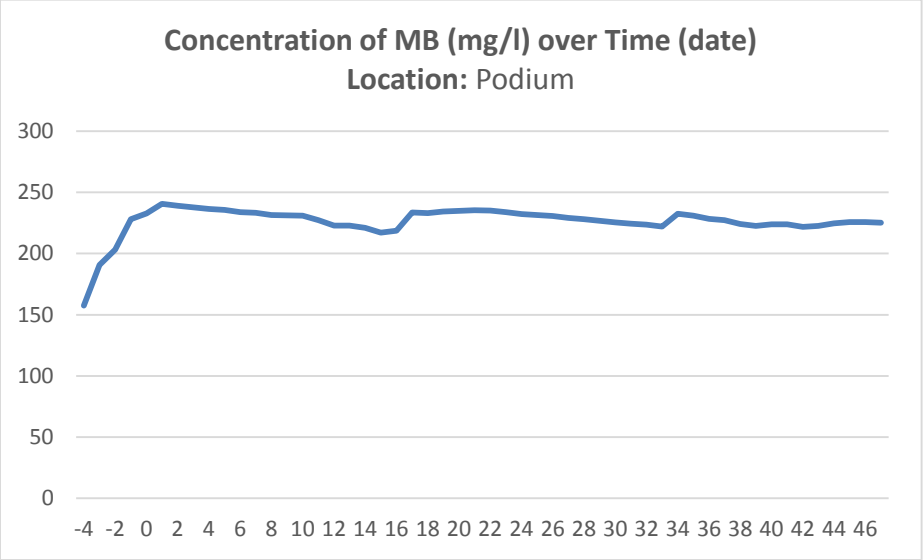

Figure B- 53. Concentration of MB (mg/l) over Time (hr), Classroom Podium Location.

Attachment 1: MB Fumigation Health and Safety Plan

Attachment 2: MB Fumigation Ambient Air Monitoring Plan

Attachment 3: MB Field Operational Guidance to New York City